

TP 14429E

**ASSESSMENT OF LOW-FLOOR TRANSIT BUS G FORCES ON REAR-FACING
WHEELCHAIR SECUREMENT SYSTEMS**



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March 2005

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16 Abstract This report presents the results of several testing scenarios of urban low-floor buses equipped with a rear-facing securement system for wheelchair passengers. Frontal crash tests at 50 km/h indicated that the deceleration on the load cell holding a wheelchair with a simulated passenger weight measured below 3 g. Extreme manoeuvring test results indicated a maximum lateral force of 0.2 g, and a longitudinal deceleration force of 0.5 g for the dummy and wheelchair, measured by accelerometers on the bus floor. The sled test results, using 3 g for the impact on a back panel mock-up with different angles, were inconclusive to determine the appropriate back angle degree, but showed that the passenger and the wheelchair would be safe under these circumstances. It was concluded that the 3 g forces as indicated in CSA Standard D435-02 were validated and that the rear-facing system is a safe system to be used in large low-floor buses.				
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16. Résumé Le rapport présente les résultats de plusieurs scénarios d'essai mettant en jeu des autobus urbains à plancher bas équipés d'un dispositif de retenue de fauteuil roulant orienté vers l'arrière. Les essais de collision frontale à 50 km/h ont révélé que la force de décélération transmise au dynamomètre piézoélectrique retenant un fauteuil roulant lesté du poids d'un occupant était inférieure à 3 g. Des accéléromètres fixés au plancher pour des essais de manoeuvrabilité extrême ont indiqué une force latérale maximale de 0,2 g, et une force de décélération longitudinale de 0,5 g, pour le mannequin et le fauteuil roulant. Les résultats des essais sur chariot d'accélération, qui génèrent une force d'impact de 3 g sur un modèle de panneau rembourré/appui dorsal en vraie grandeur incliné à différents angles, n'ont pas permis de déterminer l'angle d'inclinaison approprié, mais ont révélé que le passager et le fauteuil roulant ne couraient aucun risque dans les conditions étudiées. Il a été conclu que la force maximale de 3 g sur laquelle est fondée la norme CSA D435-02 est valide, et que le dispositif de retenue de fauteuil roulant orienté vers l'arrière peut être utilisé en toute sécurité dans un autobus à plancher bas de gros gabarit.				
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Mr. Paul Fogh-Dohnsmidt of Medichair in Victoria. Medichair provided all wheelchairs, scooters, electric and power chairs.

Mr. Jean-Marc Girardin of Q-straint. Q-straint provided support and a Hybrid II dummy.

EXECUTIVE SUMMARY

The results of several testing scenarios are presented for urban low-floor buses equipped with rear-facing securement systems for wheelchair passengers. Frontal crash tests were carried out to investigate the amount of g forces a passenger in a wheelchair would be exposed to during a vehicle collision. Extreme manoeuvring tests were conducted to determine longitudinal and lateral g forces in the bus, and to observe the reaction of a crash test dummy in different types of wheelchairs under severe driving conditions. Sled tests were performed to observe how the dummy and the wheelchair types reacted when exposed to a 3 g impact on a variety of back panel angles. The implications of these results for the industry and for standards are discussed. Recommendations are presented to improve the safety of the passenger and the design of the rear-facing securement.

Frontal Crash Tests

Four crash tests were conducted, each a full frontal crash of a bullet car into a stationary bus. The raw data indicated that the floor-mounted 10 g accelerometers saturated during the impacts, so the data from that group was disregarded. The 100 g accelerometer data was processed as per SAE Standard J211-1. The data was filtered with a 60 Hz finite impulse response filter. The processed data from the longitudinal direction accelerometer from Crash 1 is presented in Figure 1.

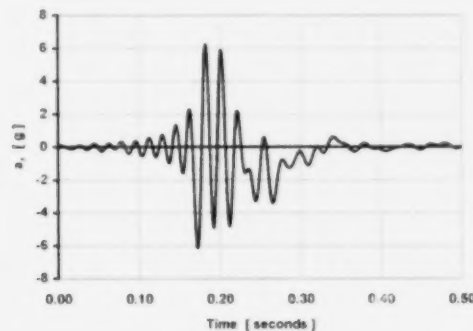


Figure 1 Crash 1 bus floor longitudinal accelerations

The floor accelerometer data exhibited ringing at about 57 Hz for about the first 100 msec (from about 0.12 seconds to 0.22 seconds) of the impact. During that time the floor accelerations ranged between +6 g and -6 g. A slight amount of negative acceleration was then evident in the accelerometer output (from about 0.22 seconds to 0.32 seconds). Although the longitudinal accelerations reached ± 6 g, the duration beyond ± 3 g was only about 10 msec for each excursion.

The ringing of the bus was evident in the output from all three floor-mounted accelerometers, although at slightly different frequencies. The output of the lateral (a_y) and vertical (a_z) accelerometers is depicted in Figure 2.

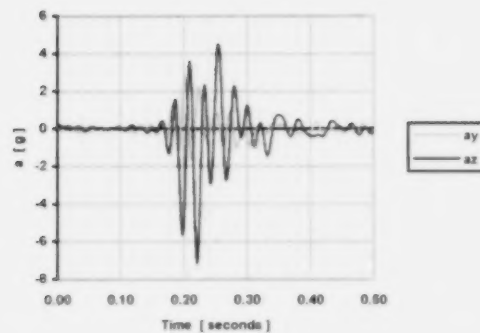


Figure 2 Crash 1 bus floor lateral (a_y) and vertical (a_z) accelerations

The event of a frontal crash in the urban transit environment is extremely rare. These results indicate that the occupant of a wheelchair in a frontal crash would be exposed to more than 3 g only for 10 msec, which the occupant would not register.

Extreme Manoeuvring Tests

A total of 36 tests were performed with four buses. Figure 5 shows the test circuit layout. The results of a single test with the 9 m Dennis Dart low-floor bus are presented in Figure 6 as an example of the most extreme, as it was the shortest and lightest bus.



Figure 3 Dummy in three-wheel scooter in rear-facing position on 9 m Dennis Dart



Figure 4 Wheelchair types and low-floor bus prepared for extreme manoeuvring testing

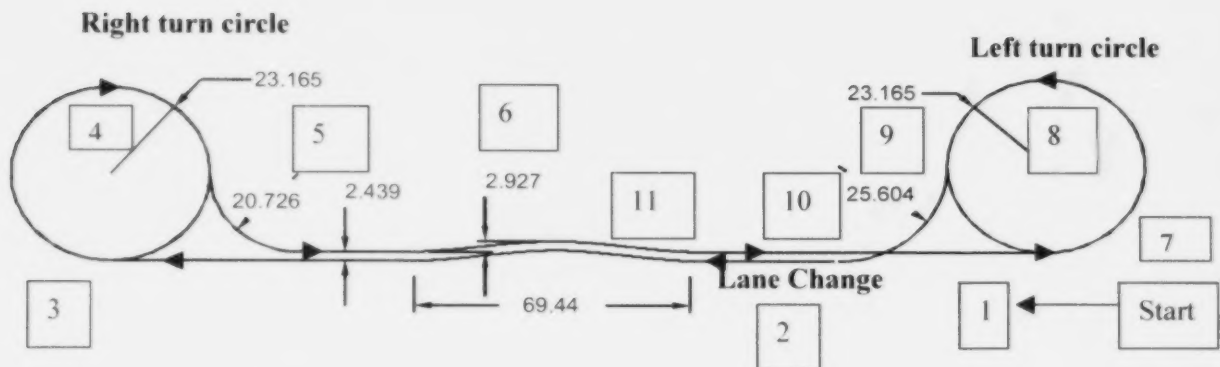


Figure 5 Extreme manoeuvring test circuit layout, (not to scale, dimensions in m)

Boxed numbers indicate critical measuring points on the test track.

1. Acceleration from start to 50 km/h
2. ISO lane change to left
3. Right turn
4. Brake in right turn
5. Right to left turn
6. ISO lane change to right
7. Left turn
8. Brake in left turn
9. Left to right turn
10. Acceleration to 50 km/h
11. Brake on straight

The longitudinal acceleration history is depicted in Figure 6. It can be seen that the bus was able to achieve approximately -0.5 g during braking, and slightly over 0.1 g for maximum acceleration. Test results from all buses showed very similar data. Longitudinal accelerations measured about 0.15 g .

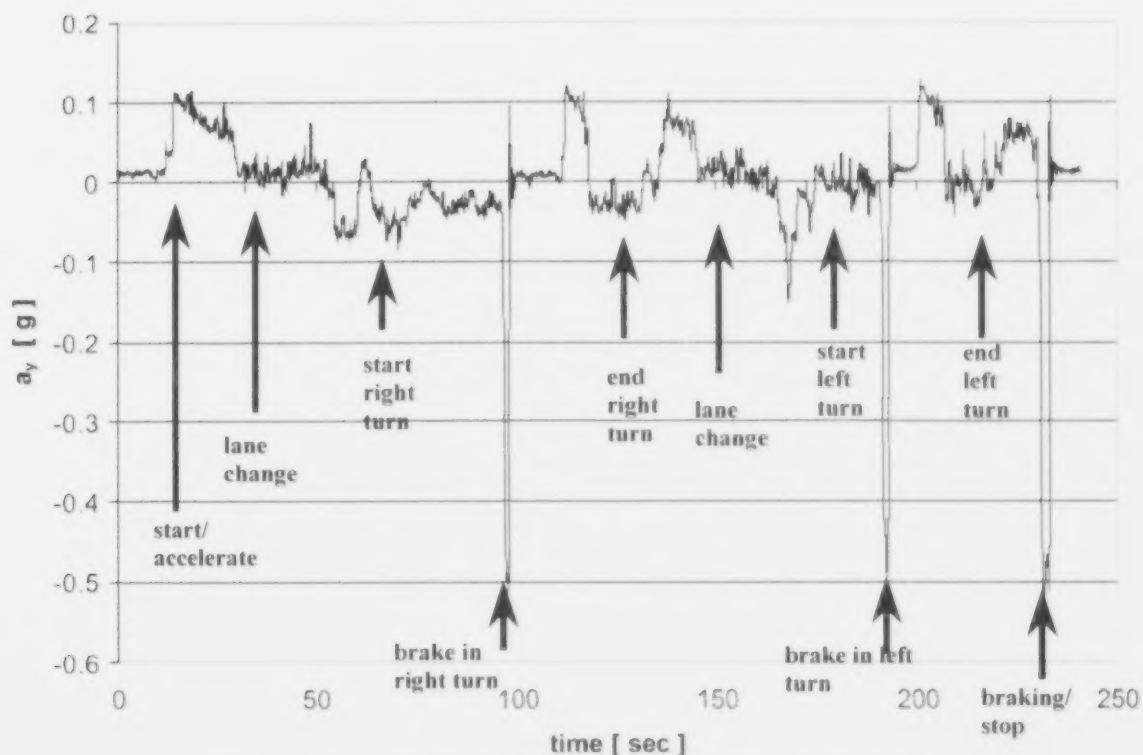


Figure 6 Longitudinal accelerations, 9 m Dennis Dart bus

The lateral acceleration history is depicted in Figure 7 (the accelerometer data is offset by approximately 0.02 g.). It can be seen that the lane change manoeuvre generated approximately 0.2 g laterally, and turning from the circle into the other direction about 0.3 g. The steady state turns were made at about 0.2 g.

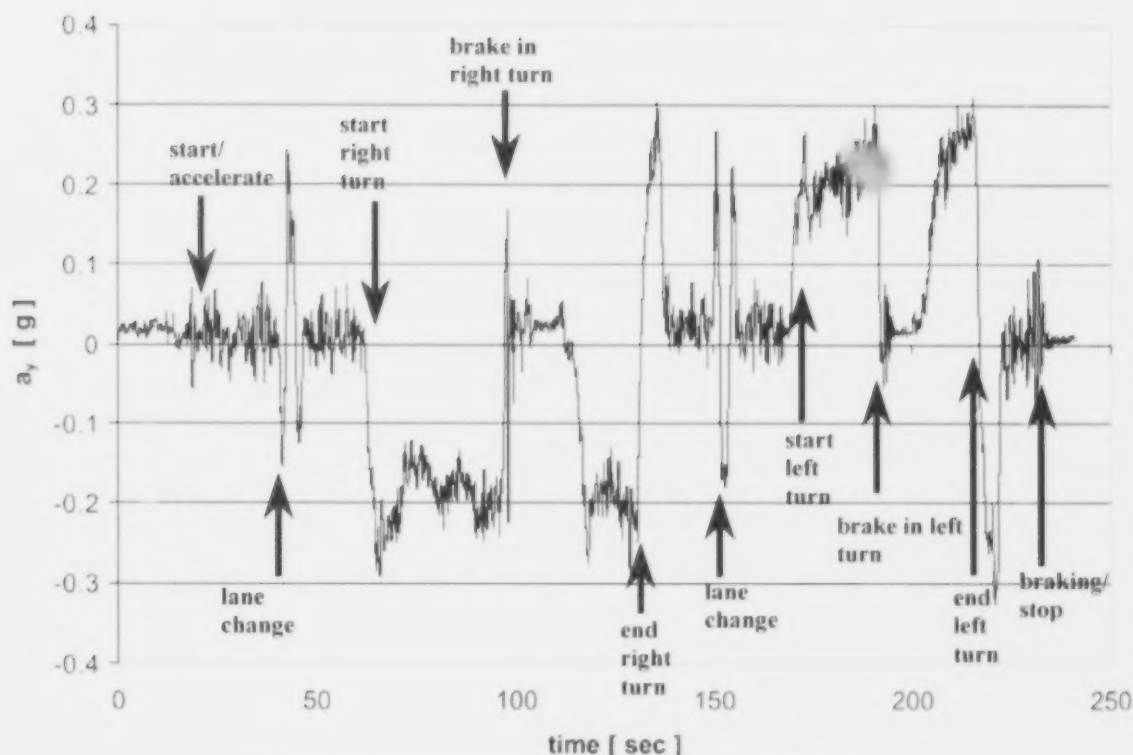


Figure 7 Lateral accelerations, 9 m Dennis Dart bus

According to the test results there seems to be very little difference in the performance of the buses as far as their size and weight are concerned. For instance, lane change manoeuvres resulted in 0.2 to 0.25 g lateral acceleration for all buses. This indicated that the 9 m Dennis Dart does not generate greater lateral accelerations than the heavy 12 m double decker. For the passenger this means that there is no significant difference in risk in using a small or large transit bus. That the smallest 9 m Dennis Dart performed equivalent to the largest 12 m double decker indicates that CSA Standard D435-02 is equally valid for a wide range of buses.

Observations for Wheelchairs and Dummy

Observations of the extreme manoeuvring tests indicated that the most stable wheelchairs were the manual, power and electric wheelchairs. The seats of these three chairs are mounted directly onto their chair frames and platforms to form one solid unit. The three- and four-wheeled scooter power platforms remained very stable during the tests, but the single-column seat mounting resulted in severe swaying of the dummy. This was even more evident in the case of the 12 m New Flyer bus, where the distance from the bus wall to the dummy was greater than in other buses due to its heating duct design. This allowed the dummy to sway severely from side to side, moving the scooter with it and lifting the rear wheels.

For the scooters, the most noticeable lateral movements of the dummy occurred when the bus was coming out of the circle and changing direction, e.g. from left turn to right, and when

accelerating within the test track's 360° circle. The severe braking in the circles and on the straight run indicated that the dummy would be in a safe position in any chair or scooter as long as it was in the upright position in front of the backrest before braking occurred. The only movement observed was the rebound of the dummy's head after contacting the backrest. It is important to note that the backrest installed in all buses did not have enough clearance from the floor to accommodate the battery packs of the scooters, electric chairs and power chairs, thus resulting in the dummy's back being too far away from the backrest.

The size of the bus did not seem to have a significant effect on the results.

Sled Tests

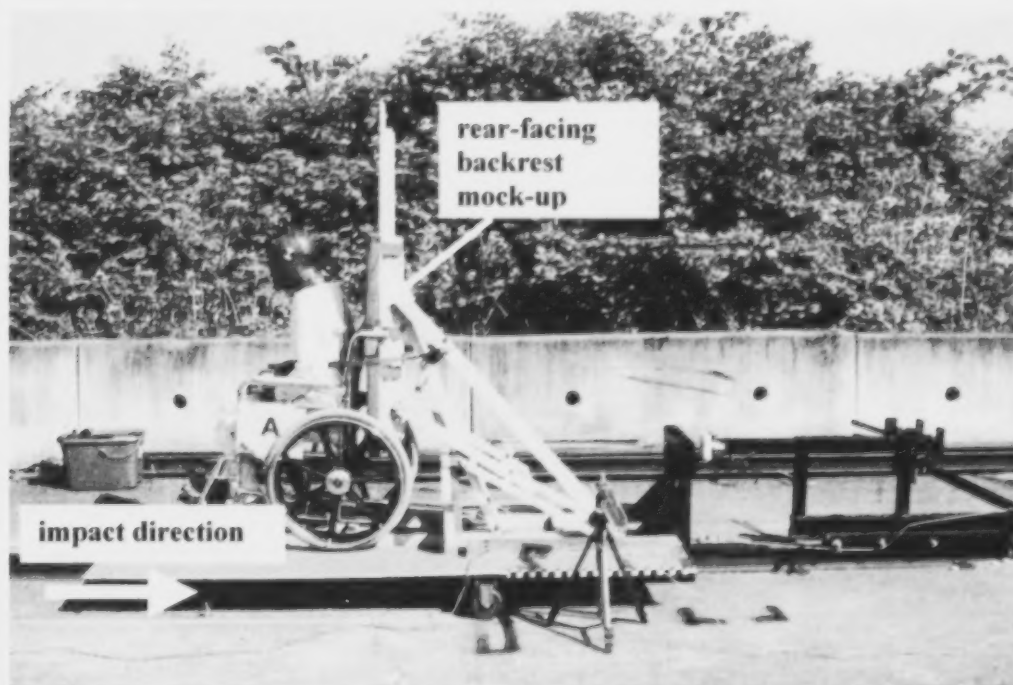


Figure 8 Sled test set-up with backrest mock-up, wheelchair and dummy

Four mobility devices with a Hybrid II dummy were tested on the sled. They were identified as chairs A, B, D and E, and each was tested in five different configurations. The configurations included various stall backrest angles, and various spacings between the dummy's head and the backrest. One objective was to produce identical deceleration pulses for all of the tests. It was found that the bending break snubber provided quite reproducible results. An example of the sled deceleration pulse is depicted in Figure 9.

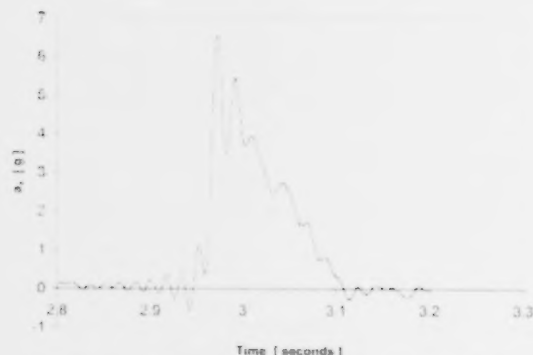


Figure 9 Example sled deceleration pulse

In Figure 9, it can be seen that the deceleration pulse exceeded 3 g for longer than 50 msec. However, in all of the tests it was noted that the dummy appeared to react favourably and remained on the mobility device, which remained in the rear-facing stall. There was a tendency for the mobility device and the dummy to rebound following the deceleration pulse.

Summary of Sled Test Observations

There were no conclusive results obtained for the correct back angle applying to all chair types. The manual and electric chairs seemed to perform best in the -4° , $+8^{\circ}$ and self-adjusting positions, whereas the scooters had less rebound in the $+4^{\circ}$ and $+8^{\circ}$ positions.

Sliding up the backrest seemed to absorb some of the impact energy, resulting in a lesser rebound of the head. It is noteworthy to mention that no batteries became loose during impact, and only in one instance did the rear wheels lift slightly. During these tests the dummy was not instrumented. Additional tests would be required to investigate what impact the rebound of the head would have with regard to possible injuries.

CSA Standard D435-02 and this Study

CSA D435-02 requires mobility aid transportation features of large accessible transit buses to be designed and to perform to ensure a safe environment to withstand frontal crash forces up to 3 g. The 3 g value was adopted by the D435 Technical Committee based on excellent transit bus accident history with standing passengers in a bus and the belief that 3 g is the maximum deceleration likely to be encountered in a frontal impact in a transit bus over 7000 kg GVWR. Similar European standards use a value of 1 g. Over the years there has been debate over the most appropriate force to use in the standards: 1 g, 3 g, 6.7 g, or even 10 g. The CSA 3 g value reflects a balance between safety and practicality in the transit environment.

One of the purposes of this study was to perform crash testing of transit buses with cars to simulate a typical frontal crash and to determine actual impact forces in the buses. The results of this crash testing confirmed the appropriateness of the 3 g value.

Upon validation of the 3 g value used in the standards, further testing on a sled using a rear-facing wheelchair station mock-up was done to learn more about the performance of the rear-facing design specified in CSA D435-02. This testing used an anthropomorphic dummy in a variety of mobility aid types exposed to 3 g impact forces while stationed in the mock-up rear-facing wheelchair station.

In addition, performance testing was carried out using a variety of accessible in-service transit buses. This testing expanded the knowledge on how passengers and mobility aids react in a rear-facing wheelchair station during aggressive driving typical of an emergency situation on the road. This information will assist in future revisions of CSA D435-02.

In-service Survey by OSU

An in-service survey project was undertaken by a research team at Oregon State University at the same time as our project, and it was agreed that collaboration between the two teams would result in benefits for the industry. Their goal was to evaluate options for securements used in Bus Rapid Transit systems through: measuring vehicle dynamics, evaluating mobility-aid responses to bus motions using rear-facing systems and side-facing securement, and evaluating user responses to the concept of rear-facing systems. The results of the study indicated that accelerations during normal driving averaged substantially below that of extreme manoeuvring. In the case of forward acceleration, it was about 0.10 g with a maximum of 0.20 g. For turns, the average during normal driving was about 0.18 g, with a maximum recorded of 0.4 g. For deceleration under normal conditions, the average was 0.19 g.

The results of the survey were remarkably similar for users and potential users. Overall, approximately 70% were enthusiastic about rear-facing securement, about 10% had no opinion and about 20% did not want to use rear-facing securement.

A final report of the project has been completed.¹

Conclusions

- The crash tests indicated that the wheelchair occupant would only be exposed to more than 3 g for 10 msec, which is not sufficient time to result in much transference of the force to the body, and therefore the change in speed of the body is very low. The event of a frontal crash would be very rare in the urban transit environment.
- The extreme manoeuvring test results rendered a maximum of 0.5 g for deceleration in a panic brake, and 0.10 g in maximum acceleration for a 9 m bus. The other buses registered 0.8 g in a panic brake and 0.15 g in maximum acceleration. Maximum lateral acceleration was 0.25 g.

¹ Hunter-Zaworski, K., and J. Zaworski, *Assessment of Rear-facing Wheelchair Accommodation on Bus Rapid Transit BRT*, Transit IDEA Project-38, August 2004

- The sled tests indicated that the different wheelchairs and the occupant would be held safely by the backrest in a 3 g crash pulse. The tests with different backrest angles were not conclusive but seemed to indicate that the occupant's rebound after impact would be favourable at +4° and with a self-adjusting back. Batteries did not become loose during these tests.
- The tests validated the 3 g figure indicated in CSA Standard D435-02 for rear-facing securements in urban buses. The load cell in the crash test indicated 2.9 g with a 12 m General Motors bus.
- The aisle stanchion was shown to be relatively successful in preventing mobility aids from moving or tipping into the aisle during the performance testing. However, there is definitely room for improvement.
- The lateral distance between the passenger's shoulder and the bus wall was too large in the 12 m New Flyer bus and allowed for swaying and tipping of the passenger's upper body in sharp turns.
- The rear-facing backrest structure, designed to CSA Standard D435-02 specifications, adequately controlled the reactions of the mobility aid and the dummy during the 3 g sled testing.
- Although the existing backrest structures in the buses were consistent with CSA D435-02, the vertical distance from the floor to the back panel was too short and did not allow for the battery packs to fit underneath, thus preventing the passenger's back from getting as close as possible to the backrest.
- The backrest panel used in the sled testing was too wide to suit some wheelchairs, despite meeting CSA D435-02 width specifications.
- During the sled testing impact, the dummy tended to ride up the +4° to +8° slope of the backrest specified in CSA D435-02. This motion would absorb some crash energy and hence is a positive feature, but it is also evidence that the height of back panel should be generous and suit a 95th percentile person.
- In the sled testing, the plastic upholstery of the back panel seemed to decrease friction, but no friction tests were conducted.
- Some wheelchair/scooter's wheels slid on the floor during the panic brake and in curves.

Recommendations

Based on the outcome of the testing, the following recommendations are made:

Design

- An improved system to prevent the wheelchairs or scooters from moving into the aisle should be designed to further minimize lateral movement and improve user convenience.
- A system should be designed with the shortest lateral distance possible between the passenger's shoulders and the side supports.
- The backrest should be designed and installed to ensure the head and back of the passenger are positioned as close as possible to the backrest panel. There should be a horizontal space behind the back panel for the large rear wheels of wheelchairs to clear so that the passenger's back comes as close as possible to the back panel.
- Vertical clearance from floor to the bottom of the back panel must be appropriate in order to allow for batteries and power packs from scooters and power chairs to fit underneath the panel and allow for the passenger's back to come as close as possible to back panel.
- The width of back panel must be appropriate to clear the handlebars of manual wheelchairs.
- The angle of the back panel should be appropriate to absorb the most energy of the passenger.
- To help control the passenger's movement during impact, the upholstery of the back panel should be high friction.
- To minimize slippage of the mobility aid on the bus floor, high-friction flooring should be used on the bus in the wheelchair compartment to increase friction for wheelchair wheels.

Operations

- The rear-facing design, as tested, was shown to be a safe system to implement into large urban buses to protect passengers using wheelchairs and scooters for normal and severe urban driving conditions, provided that the brakes of the wheelchairs/scooters are applied and that an aisle-side anti-tipping system is in place to prevent wheelchairs and scooters from moving/tipping into the aisle. Rear-facing mobility aid passengers should always be positioned as close as possible to the backrest.
- The rear-facing system should be installed as close to the bus wall as possible to keep the aisle free and to keep the passenger's upper body as close as possible to the wall for lateral support.

Standards

- The 3 g forces as indicated in CSA Standard D435-02 were validated by the tests to be appropriate.
- The geometry of the backrest as specified should be reviewed to ensure it properly accommodates the majority of mobility aids. Based on the testing experience, the backrest would be more accommodating if its maximum width were less than the 420 mm specified, and its height from the floor more than the 350 mm specified.

R&D

- Further R&D should be undertaken to:
 - Develop a more effective and efficient aisle support
 - Determine optimum back panel geometry (width, height, distance from floor)
 - Determine optimum back panel angles
 - Identify appropriate high-friction surfaces for back panel upholstery and bus floor
 - Study risk of injury to the passenger's head and body during 3 g frontal impacts when riding in the rear-facing system in a full-size bus

SOMMAIRE

Le rapport présente les résultats de plusieurs scénarios d'essai mettant en jeu des autobus urbains à plancher bas équipés d'un dispositif de retenue de fauteuil roulant orienté vers l'arrière. Des essais de collision frontale ont permis de déterminer les forces g que subirait un passager occupant un fauteuil roulant au moment d'une collision. Des essais de manoeuvrabilité extrême ont aussi été réalisés pour enregistrer les forces g longitudinales et latérales exercées sur l'autobus, et pour observer la réaction d'un mannequin d'essai placé dans plusieurs types de fauteuils roulants, dans des conditions de conduite difficiles. Enfin, des essais sur chariot d'accélération ont été menés afin d'observer les réactions du mannequin et des fauteuils roulants à un impact de 3 g sur un panneau rembourré/appui dorsal fixé à divers angles d'inclinaison. Les incidences de ces résultats pour les acteurs de l'industrie et pour les normes sont analysées. Finalement, des recommandations sont formulées pour améliorer la sécurité du passager et la conception du dispositif de retenue de fauteuil roulant orienté vers l'arrière.

Essais de collision frontale

Quatre essais de collision ont été réalisés; il s'agissait chaque fois d'une collision avant entre une voiture bélier et un autobus immobilisé. Les données brutes ont indiqué que les accéléromètres de 10 g fixés au plancher saturaient au moment des impacts; ces données ont donc été écartées. Les données des accéléromètres de 100 g ont été traitées conformément à la norme J211-1 de la SAE. Les données ont été filtrées par un filtre 60 Hz à réponse impulsionnelle finie. Les données traitées, enregistrées par l'accéléromètre dans l'axe longitudinal lors de la collision 1, sont présentées à la figure 1.

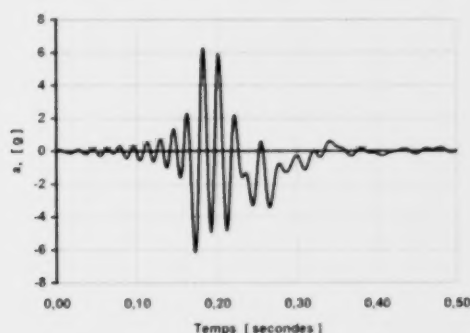


Figure 1 : Collision 1 - Accélérations longitudinales transmises au plancher de l'autobus

Les données des accéléromètres de plancher ont affiché des oscillations autour de 57 Hz pendant les 100 premières ms de l'impact ou à peu près (de 0,12 s à 0,22 s). Pendant ce temps, les forces d'accélération exercées sur le plancher variaient de +6 g à -6 g . Une légère accélération négative apparaît sur la sortie de l'accéléromètre (de 0,22 s à 0,32 s, plus ou moins). Même si les accélérations longitudinales ont atteint $\pm 6 g$, chaque excursion au-delà de $\pm 3 g$ a duré à peine 10 ms.

Des oscillations de fréquences légèrement différentes ont été enregistrées par les trois accéléromètres fixés au plancher. La figure 2 présente les sorties des accéléromètres latéral (a_y) et vertical (a_z).

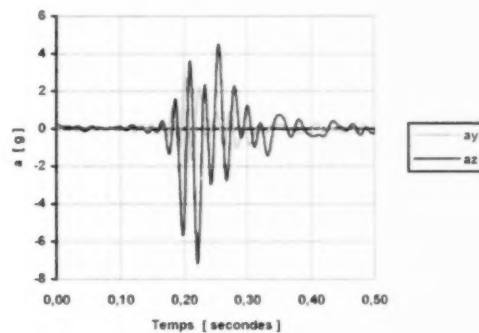


Figure 2 : Collision 1 - Accélérations latérale (a_y) et verticale (a_z) transmises au plancher de l'autobus

Les collisions frontales mettant en cause un autobus urbain sont extrêmement rares. Ces résultats indiquent que l'occupant d'un fauteuil roulant, lors d'une collision frontale, serait soumis à une force de 3 g pendant seulement 10 ms. Il n'en ressentirait donc pas les effets.

Essais de manoeuvrabilité extrême

Au total, 36 essais sur route ont été réalisés, avec quatre autobus. La figure 5 illustre le circuit parcouru au cours de ces essais. Les résultats d'un seul essai, réalisé avec un autobus à plancher bas Dennis Dart de 9 m, sont présentés à la figure 6. Ces résultats représentent un cas extrême, car cet autobus était le plus court et le plus léger des véhicules testés.



Figure 3 : Mannequin dans un triporteur, dos à la circulation, à bord d'un Dennis Dart de 9 m



Figure 4 : Fauteuils roulants et autobus à plancher bas avant les essais de manoeuvrabilité extrême

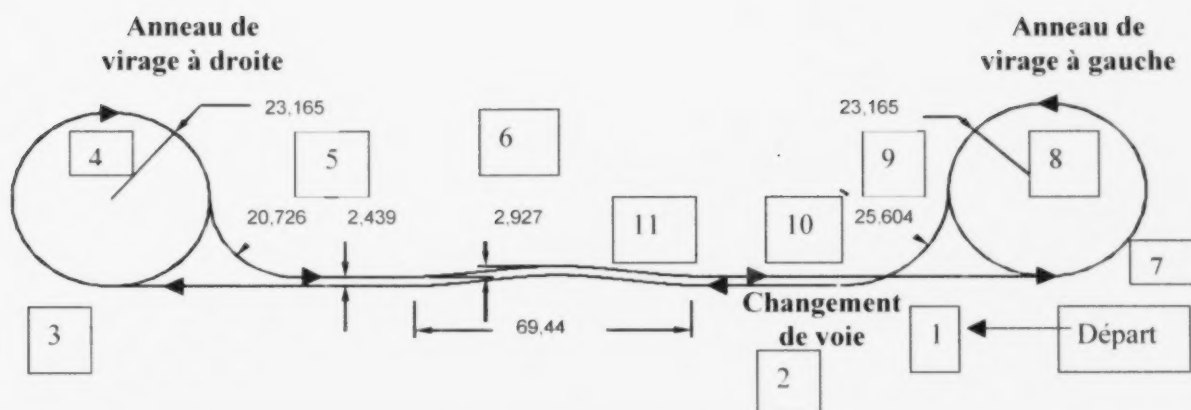


Figure 5 : Circuit de l'essai de manoeuvrabilité extrême (non à l'échelle, dimensions en mètres)

Les chiffres dans les cases indiquent les points de mesure critiques le long du circuit.

1. Accélération de 0 à 50 km/h
2. Changement de voie ISO vers la gauche
3. Virage à droite
4. Freinage en virage vers la droite
5. De virage à droite à virage à gauche
6. Changement de voie ISO vers la droite
7. Virage à gauche
8. Freinage en virage vers la gauche
9. De virage à gauche à virage à droite
10. Accélération à 50 km/h
11. Freinage en ligne droite

La figure 6 illustre l'historique des accélérations longitudinales. On peut voir que les freinages génèrent une force d'environ $-0,5\text{ g}$ et que l'accélération maximale dépassait légèrement $0,1\text{ g}$. Les résultats des essais étaient très similaires d'un autobus à l'autre. Les accélérations longitudinales étaient d'environ $0,15\text{ g}$.

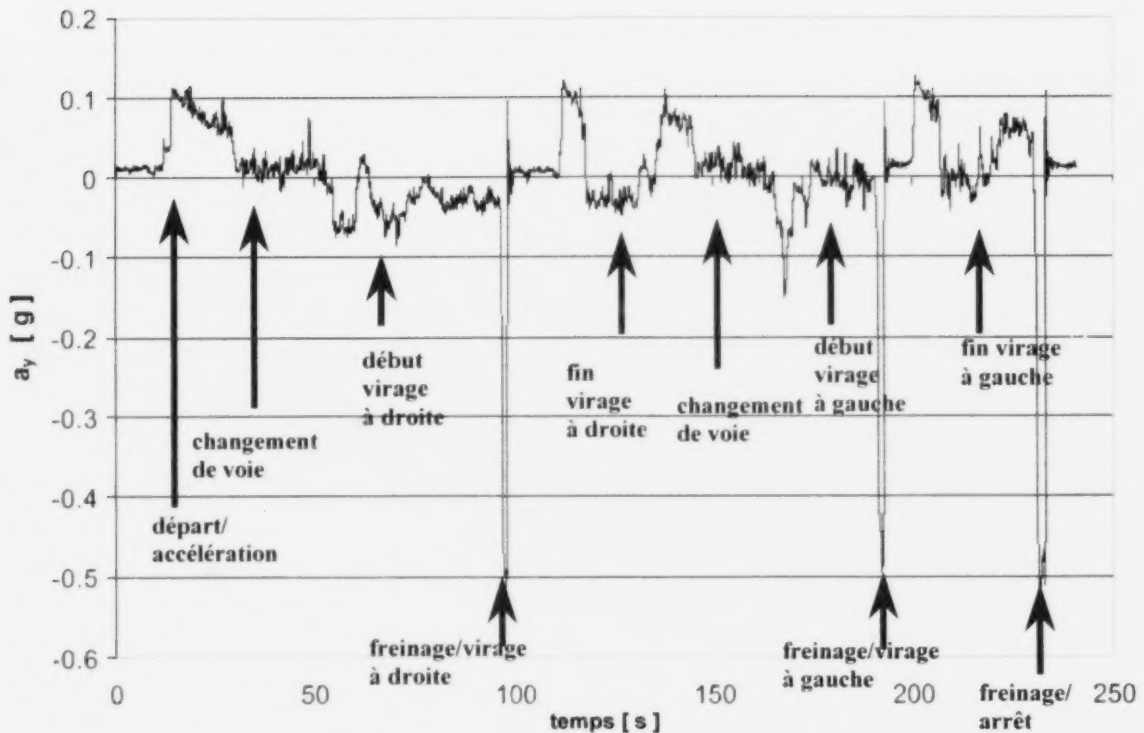


Figure 6 : Accélérations longitudinales, autobus Dennis Dart de 9 m

L'historique des accélérations latérales est reproduit à la figure 7 (les données de l'accéléromètre sont décalées d'environ 0,02 g). On peut voir que la manœuvre de changement de voie a produit une force latérale d'environ 0,2 g, et que de quitter l'anneau pour la ligne droite engendrait une force d'environ 0,3 g. Les virages continus se faisaient sous une force d'environ 0,2 g.

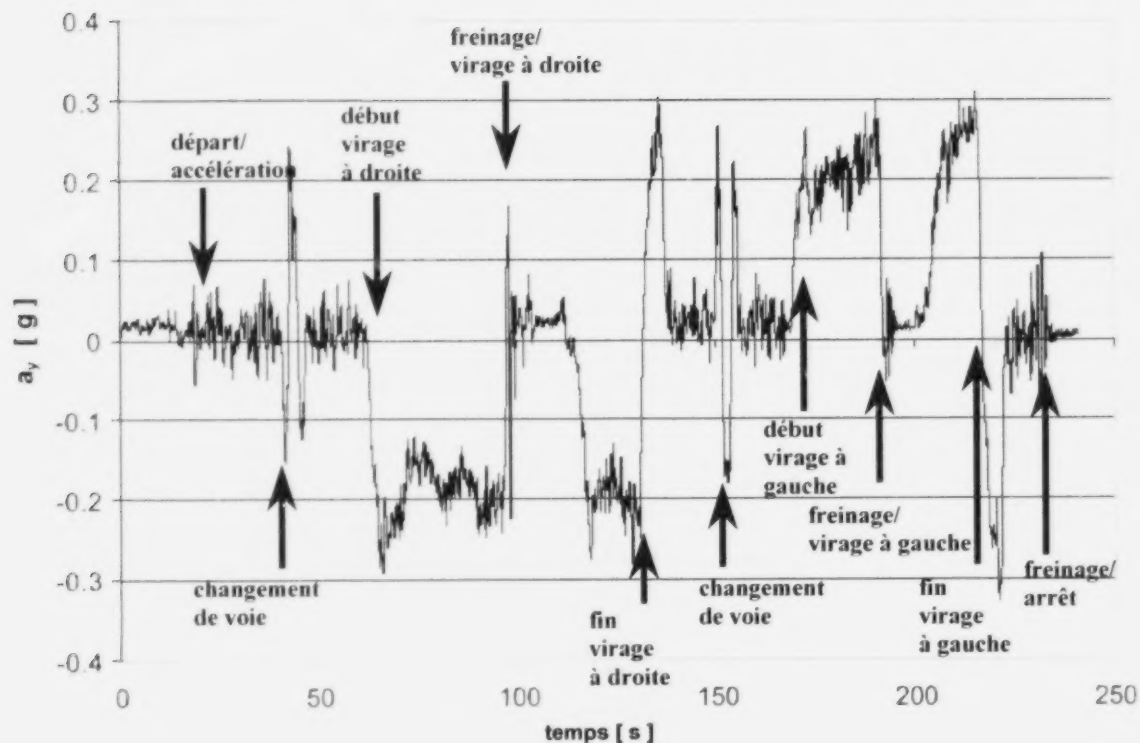


Figure 7 : Accélérations latérales, autobus Dennis Dart de 9 m

Selon les résultats des essais, il semble y avoir très peu de différences entre les performances des autobus de dimensions et de poids différents. Par exemple, les manœuvres de changement de voie ont produit des accélérations latérales de 0,2 à 0,25 g dans tous les autobus. Autrement dit, les accélérations latérales n'étaient pas plus fortes dans le Dennis Dart de 9 m que dans le gros autobus de 12 m à deux étages. Pour le passager, cela signifie que prendre un gros autobus ou un petit ne change pas grand chose au risque. Que le petit Dennis Dart de 9 m ait eu une performance équivalente à celle du gros véhicule de 12 m à deux étages indique que la norme CSA D435-02 pourrait être tout aussi valide pour un large éventail d'autobus.

Observations concernant les fauteuils roulants et les mannequins

Selon les observations faites au cours des essais de manoeuvrabilité extrême, les fauteuils roulants les plus stables sont les fauteuils manuels et électriques. Le siège de ces fauteuils est monté directement sur le châssis et la plate-forme, et l'ensemble forme un bloc solidaire. Dans le cas des *scooters* (triporteurs et quadriporteurs), la plate-forme est demeurée très stable pendant les essais, mais le siège, monté sur une colonne, a fait fortement osciller le mannequin. Ces oscillations étaient encore plus accentuées dans le cas de l'autobus New Flyer de 12 m, du fait que la distance entre la paroi de l'autobus et le mannequin y est plus grande que dans les autres

autobus, car c'est là que passe le conduit d'air chaud. On a vu le mannequin s'incliner fortement de chaque côté et bouger avec le *scooter*, et les roues arrière de ce dernier se soulever.

Toujours dans le cas des *scooters*, c'est lorsque l'autobus quittait l'anneau et changeait de direction, p. ex., lorsque le volant était ramené de la gauche vers la droite, et lorsque l'autobus accélérât dans l'anneau, qu'ont été observés les mouvements latéraux les plus amples chez le mannequin. Les manœuvres de freinage brusque en courbe et en ligne droite ont révélé que le mannequin serait dans une position sûre, quel que soit le fauteuil roulant et le *scooter*, à condition qu'il soit bien droit vis-à-vis le panneau rembourré avant que survienne le coup de frein. Le seul mouvement observé était le rebondissement de la tête du mannequin sur le panneau rembourré. Il est important de noter que dans tous les autobus, le dégagement entre le dossier et le plancher n'était pas suffisant pour accueillir les blocs d'alimentation des *scooters* et des fauteuils électriques. Le dos du mannequin était donc beaucoup trop éloigné du panneau rembourré.

Les dimensions de l'autobus n'ont pas semblé avoir d'effet significatif sur les résultats.

Essais sur chariot d'accélération

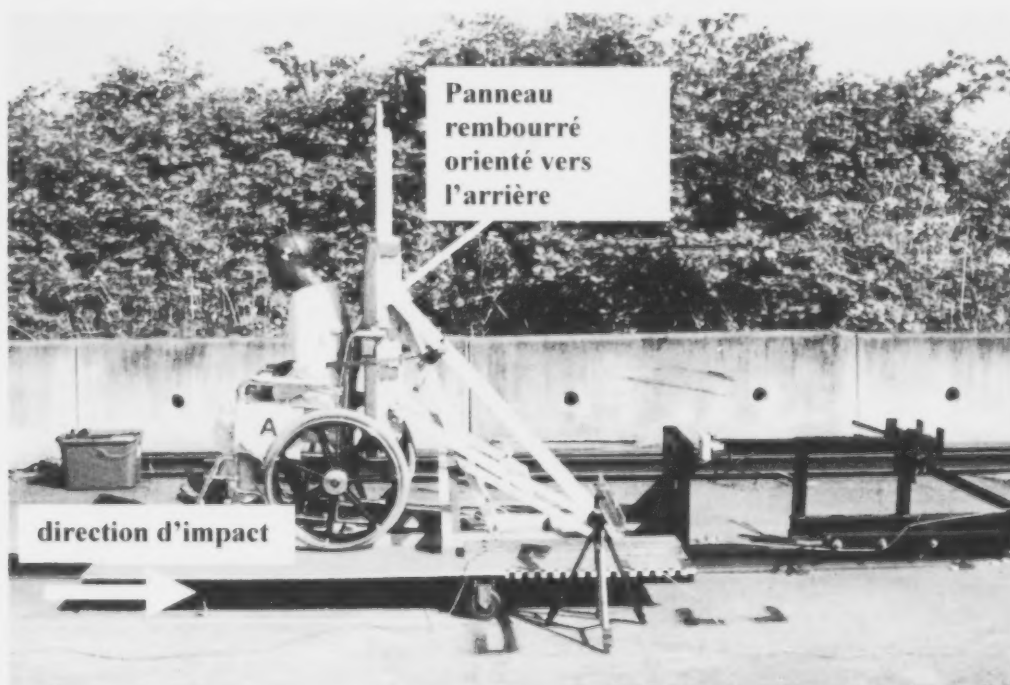


Figure 8 : Montage d'essai sur chariot d'accélération avec panneau rembourré, fauteuil roulant et mannequin

Quatre aides à la mobilité (ou moyens de déplacement) portant un mannequin Hybrid II ont été testées. Elles étaient désignées fauteuil A, B, D et E, et chacune a été testée dans cinq

configurations différentes, soit différents degrés d'inclinaison du panneau rembourré, et divers espacements entre la tête du mannequin et le panneau. Un des objectifs était de produire des impulsions de décélération identiques pour tous les essais. Le butoir d'arrêt s'est révélé donner des résultats reproductibles. La figure 9 donne un exemple d'impulsion de décélération du chariot.

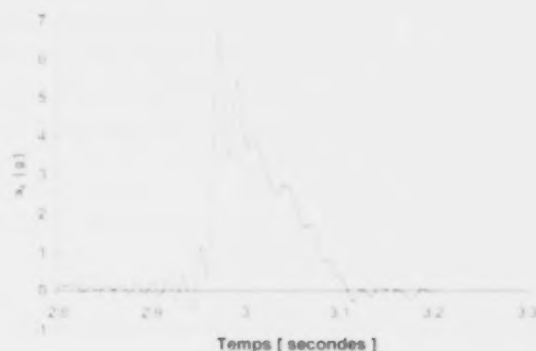


Figure 9 : Exemple d'impulsion de décélération transmise au chariot

Comme le montre la figure 9, l'impulsion de décélération a dépassé 3 g pendant plus de 50 ms. Mais à chacun des essais, le mannequin a semblé bien réagir et est demeuré dans le fauteuil, lequel n'a pas bougé de sa position orientée vers l'arrière. Le fauteuil et le mannequin avaient tendance à rebondir après l'impulsion de décélération.

Résumé des observations concernant les essais sur chariot d'accélération

Les essais n'ont pas donné de résultat concluant concernant l'angle d'inclinaison « idéal » du panneau rembourré, applicable à tous les types de fauteuils. Les fauteuils manuel et électrique semblaient afficher leurs meilleures performances dans les positions -4° , $+8^{\circ}$ et à autorégulation, tandis que les *scooters* rebondissaient moins dans les positions $+4^{\circ}$ et $+8^{\circ}$.

Le coulissage vers le haut du panneau rembourré a semblé se traduire par une meilleure absorption de l'énergie d'impact, et par un rebondissement moindre de la tête. Il est important de mentionner qu'en aucun cas les batteries ne se sont détachées pendant l'impact, et dans un seul cas, les roues arrière se sont légèrement soulevées. Au cours des essais, le mannequin n'était pas instrumenté. D'autres essais devraient être entrepris pour examiner dans quelle mesure le rebondissement de la tête pourrait entraîner des blessures.

La norme CSA D435-02 et la présente étude

La norme CSA D435-02 exige que les dispositifs de retenue des aides à la mobilité des autobus urbains de gros gabarit pour le transport accessible soient conçus et fonctionnent de façon à protéger les passagers lorsque survient une collision frontale générant des forces allant jusqu'à

3 g. Le Comité technique responsable de l'élaboration de la norme D435 s'est fondé sur une force de décélération maximale de 3 g en raison de l'excellent dossier de sécurité des autobus urbains transportant des passagers debout, et parce qu'il considérait cette valeur représentative de la force de décélération maximale qu'il est raisonnablement possible de subir lors d'une collision frontale à bord d'un autobus urbain de plus de 7 000 kg de PNBV (poids nominal brut du véhicule). Les normes européennes se fondent quant à elles sur une valeur de 1 g. Au cours des ans, on a beaucoup discuté de la valeur qu'il convenait d'assigner à la force g dans les normes : 1 g, 3 g, 6,7 g, ou même 10 g. La force de décélération maximale de 3 g adoptée par la CSA permet un bon équilibre entre les impératifs de sécurité et de commodité.

Un des buts de cette étude était de mener des essais de collision entre des autobus urbains et des voitures de façon à simuler une collision frontale type, et de déterminer les forces d'impact réelles engendrées dans l'autobus. Les résultats de ces essais de collision ont confirmé le bien-fondé de la valeur 3 g.

Une fois validée la valeur 3 g, des essais sur chariot d'accélération portant un modèle en vraie grandeur d'un emplacement pour fauteuil roulant orienté vers l'arrière ont été réalisés, afin d'étudier le rendement du concept «orientation vers l'arrière» décrit dans la norme CSA D435-02. Ces essais faisaient appel à un mannequin anthropomorphique occupant divers types d'aides à la mobilité immobilisés dans un emplacement pour fauteuil roulant faisant face à l'arrière et soumis à des forces d'impact de 3 g.

De plus, des essais sur route ont été réalisés à l'aide d'un éventail d'autobus urbains pour transport accessible en service. Ces essais ont permis de mieux comprendre comment les passagers et les aides à la mobilité occupant un emplacement pour fauteuil roulant orienté vers l'arrière réagissent lors de manœuvres de conduite routière brusques typiques d'une situation d'urgence. Ces données seront utiles lors des révisions futures de la norme CSA D435-02.

Étude en service par l'OSU

En même temps que notre projet était lancé, une équipe de chercheurs de l'Oregon State University (OSU) entreprenait une étude en service réel. Il a alors été convenu qu'une collaboration entre les deux équipes bénéficierait à l'industrie. Le but de l'équipe de l'OSU était d'évaluer les divers dispositifs de retenue utilisés par les réseaux d'autobus en site propre, en mesurant la dynamique des véhicules, en évaluant les réactions des aides à la mobilité aux mouvements de l'autobus, selon leur orientation (vers l'arrière ou le côté), et en évaluant les réactions des usagers à l'idée de faire face à l'arrière. Les résultats de l'étude ont indiqué que les accélérations moyennes enregistrées en conduite normale étaient très faibles par rapport à celles enregistrées lors de manœuvres extrêmes. Ainsi, l'accélération avant était d'environ 0,10 g, avec un maximum de 0,20 g. Dans les virages, la force moyenne en conduite normale était d'environ 0,18 g, avec un maximum enregistré de 0,4 g. Quant à la décélération, elle atteignait en moyenne 0,19 g dans des conditions normales.

Les résultats de l'enquête étaient remarquablement similaires pour les usagers et les usagers potentiels. Dans l'ensemble, environ 70 p. 100 étaient enthousiastes à propos de l'orientation vers l'arrière, quelque 10 p. 100 n'avaient pas d'opinion, et environ 20 p. 100 refusaient de voyager dos à la circulation.

Un rapport final a été rédigé au terme du projet².

Conclusions

- Les essais de collision ont révélé que l'occupant du fauteuil roulant subirait une force supérieure à 3 g pendant seulement 10 ms, ce qui est trop court pour produire un transfert de force significatif au corps, et pour entraîner une variation importante de la vitesse du corps. Par ailleurs, les collisions frontales sont des événements très rares en transport urbain.
- Les essais de manoeuvrabilité extrême ont indiqué, pour un autobus de 9 m, une décélération maximale de 0,5 g, lors d'un freinage d'urgence, et une accélération maximale de 0,10 g. Les autres autobus ont enregistré une force de 0,8 g, lors d'un freinage d'urgence, et une accélération maximale de 0,15 g. L'accélération latérale maximale a été de 0,25 g.
- Les essais sur chariot d'accélération ont indiqué que les différents fauteuils roulants, et l'occupant, seraient bien protégés par le panneau rembourré en cas d'impact produisant une impulsion de décélération de 3 g. Sans être concluants, les essais mettant en jeu différents angles d'inclinaison du panneau ont semblé indiquer que le rebond de l'occupant après l'impact serait raisonnable à un angle de +4° et avec un panneau autorégleur. Les batteries ne se sont pas détachées au cours de ces essais.
- Les essais ont permis de valider la valeur de 3 g sur laquelle est fondée la norme CSA D435-02 pour la force de décélération maximale transmise au dispositif de retenue de fauteuil roulant orienté vers l'arrière dans les autobus urbains. Lors de l'essai de collision avec un autobus General Motors de 12 m, le dynamomètre piézoélectrique a indiqué 2,9 g.
- La tige d'appui, du côté de l'allée centrale, s'est révélée relativement efficace à empêcher les aides à la mobilité de se déplacer ou de basculer dans l'allée au cours des essais sur route. Mais il y a indiscutablement place à l'amélioration.
- La distance latérale entre l'épaule du passager et la paroi de l'autobus était trop grande dans l'autobus New Flyer de 12 m. On a donc noté un balancement de côté et d'avant en arrière du haut du corps dans les virages serrés.

² Hunter-Zaworski, K., and J. Zaworski, *Assessment of Rear-facing Wheelchair Accommodation on Bus Rapid Transit BRT*, Transit IDEA Project-38, August 2004

- Le panneau (ou barrière) rembourré, conçu conformément aux prescriptions de la norme CSA D435-02, a réussi à bien maintenir l'aide à la mobilité et le mannequin soumis à une force de 3 g au cours des essais sur chariot d'accélération.
- Les panneaux rembourrés dont étaient équipés les autobus testés étaient conformes à la norme CSA D435-02, mais le dégagement n'était pas assez grand entre le plancher et le panneau pour que le bloc-batterie puisse s'y loger : le passager ne pouvait donc pas s'approcher suffisamment du panneau pour s'y adosser.
- Le panneau rembourré utilisé pour les essais sur chariot d'accélération était trop large pour certains fauteuils roulants, même s'il était conforme aux prescriptions de la norme CSA D435-02.
- Lors des essais sur chariot d'accélération, le mannequin, sous l'effet de l'impact, avait tendance à remonter le long du panneau rembourré incliné selon un angle compris entre +4° et +8°, comme le prescrit la norme CSA D435-02. Ce mouvement absorbe une partie de l'énergie d'impact, ce qui est positif, mais il indique également la nécessité d'un panneau rembourré aux dimensions généreuses, pouvant convenir à une personne du 95^e centile.
- Lors des essais sur chariot d'accélération, le recouvrement en plastique du panneau rembourré a semblé diminuer le frottement, mais aucun essai de frottement n'a été mené.
- Les roues de certains fauteuils roulants et *scooters* ont glissé sur le plancher au cours des freinages d'urgence et dans les courbes.

Recommandations

À la lumière des résultats des essais, il est recommandé ce qui suit :

Conception

- Concevoir un système amélioré pour empêcher les fauteuils roulants ou les *scooters* d'être déportés dans l'allée centrale, pour réduire au minimum les mouvements latéraux et pour améliorer le confort de l'utilisateur.
- Concevoir un système qui laisse le moins de distance latérale possible entre les épaules du passager et la structure latérale.
- Concevoir et installer le panneau rembourré de façon que la tête et le dos du passager puissent s'en approcher au plus près. Prévoir un dégagement horizontal derrière le panneau pour que les grandes roues arrière des fauteuils roulants puissent s'y loger, et que le dos du passager puisse s'approcher le plus possible du panneau.

- Le dégagement vertical entre le plancher et le bas du panneau doit être suffisant pour que les batteries et blocs d'alimentation des *scooters* et fauteuils électriques puissent passer sous le panneau, et que le dos du passager puisse s'approcher le plus possible du panneau.
- La largeur du panneau rembourré doit être telle que les poignées d'un fauteuil manuel puissent passer de chaque côté.
- L'angle d'inclinaison du panneau doit permettre l'absorption du maximum d'énergie du passager.
- Pour que le passager soit bien maintenu pendant l'impact, le recouvrement du panneau rembourré doit présenter un coefficient de frottement élevé.
- Pour réduire au minimum le glissement de l'aide à la mobilité sur le plancher de l'autobus, le plancher de l'emplacement réservé à un fauteuil roulant doit être revêtu d'un matériau à coefficient de frottement élevé, afin d'accroître le frottement des roues du fauteuil roulant.

Exploitation

- Le système à orientation vers l'arrière, celui qui a été testé, s'est révélé un système qui peut être utilisé en toute sécurité dans les autobus urbains de gros gabarit, car il protège adéquatement les passagers en fauteuil roulant et en *scooter* dans les conditions normales et extrêmes de conduite urbaine, à condition que les freins de l'aide à la mobilité soient appliqués et qu'un système soit mis en place pour empêcher le fauteuil roulant et le *scooter* de se déporter/basculer dans l'allée centrale. L'occupant d'une aide à la mobilité faisant face à l'arrière devrait toujours être placé le plus près possible du panneau rembourré.
- Le dispositif de retenue de fauteuil roulant orienté vers l'arrière devrait être installé le plus près possible de la paroi de l'autobus pour garder l'allée centrale libre et pour que le passager puisse y appuyer le haut de son corps.

Normes

- Les essais ont confirmé la validité de la valeur 3 g sur laquelle est fondée la norme CSA D435-02.
- Il y a lieu de revoir les dimensions du panneau (ou barrière) rembourré prévu par la norme afin qu'elle puisse convenir à la plupart des aides à la mobilité. À la lumière des essais, ce panneau serait plus pratique si sa largeur était inférieure aux 420 mm prescrits, et si sa hauteur par rapport au plancher était supérieure aux 350 mm prescrits.

R&D

- D'autres travaux de R&D devraient être entrepris pour :
 - mettre au point un appui plus adéquat et efficace du côté de l'allée centrale
 - déterminer les dimensions optimales du panneau rembourré (largeur, hauteur, distance par rapport au plancher)
 - déterminer les angles d'inclinaison optimaux du panneau rembourré
 - déterminer des revêtements à fort coefficient de frottement pour le panneau rembourré et le plancher de l'autobus
 - étudier le risque que court le passager d'être blessé à la tête et au corps lors d'un choc frontal de 3 g, alors qu'il occupe un emplacement réservé pour fauteuil roulant orienté vers l'arrière, à bord d'un autobus de gros gabarit

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1. INTRODUCTION

This report presents the results of several testing scenarios of urban buses equipped with a rear-facing securement system for wheelchair passengers. The report discusses the implications of these results for the industry and for standards. It also outlines recommendations that would improve the safety of the passenger and the design of the rear-facing securement.

The testing consisted of three major tasks. In the first, full-scale crash tests of cars and buses were performed. In those tests, the aim was to determine the accelerations that the occupant of a rear-facing wheelchair would experience during a vehicle collision. In the second set of extreme manoeuvring tests, floor accelerations were measured in a variety of buses as they were manoeuvred through a set course, again to determine the accelerations the occupants would experience. Finally, a series of sled tests was conducted, in which a mock-up of a rear-facing wheelchair stall was decelerated. An anthropomorphic test device (dummy) was placed in a wheelchair, which in turn was positioned in the wheelchair stall for the sled tests. All of these tests were performed by Innovative Vehicle Testing Ltd. (IVT) at the Boundary Bay Facilities of the Pacific Traffic Education Centre (PTEC).

At the same time a complementary project was carried out at Oregon State University, assessing rear-facing wheelchair systems for accommodation in Bus Rapid Transit (BRT) systems [1]. Both teams agreed to collaborate on data (user surveys and bus testing) for the benefit of users, operators and manufacturers. Some of the Oregon results are summarized in this report.

1.1 Background

With the introduction of low-floor buses and the increasing cost and demand of paratransit, there has been an increasing interest in Canada and the U.S. in making conventional buses more accessible to people with disabilities. Boarding and securement technologies are two of the most important considerations in achieving this goal of wider accessibility. Most operators in Canada are converting their fleets into low-floor buses and many are installing rear-facing wheelchair securement systems. For buses in the U.S., stringent standards exist (Americans with Disabilities Act) that require securement of passengers with mobility aids. These standards are in stark contrast with studies and experience in Europe, where no securement system is required at all for passengers in wheelchairs on transit buses.

The new CSA standard D435-02 [2], along with recent surveys in Canada and the U.S. [3,4,5], reveal a significant concern. The CSA D435-02 standard and existing rear-facing mobility aid systems were developed on the basis of subjective estimates of the forces the securement systems should be required to withstand. No tests had been performed to determine actual crash forces in buses over 7,000 kg. CSA Standard D435-02 treats all transit buses over 7,000 kg to be equal, even though they may range in gross vehicle weight from 7,000 kg to over 25,000 kg.

The rear-facing design consists of an open area along the side of a bus wall, with a load-bearing head- and backrest, and an aisle-facing support. In this configuration, the person in the wheelchair faces to the rear, so that in cases of severe deceleration, the person in the wheelchair backs into and is protected by the load-bearing head- and backrest. The aisle-facing support

prevents the wheelchair from swerving/tipping into the aisle. The advantage of the concept is that it accommodates almost all wheelchair and scooter types and sizes and does not require the use of belts or hooks, thus providing total independence to the wheelchair user.

The rear-facing design presents the wheelchair passenger with:

- the independent use of public transit low-floor buses in a dignified way,
- no damage to wheelchairs and scooters by attaching belts and hooks,
- no physical, undignified contact with drivers,
- no dirty or soiled belts in contact with clothes.

For the transit operator the advantages include:

- reduction of dwell time from 3 minutes to about 1 minute per passenger,
 - no driver involvement, which speeds up operation, and eliminates injuries and driver's downtime,
 - no maintenance and replacement costs for belts,
- no hazards for other passenger from loose belts.

1.2 Purpose of this Study

The purpose of this study was to investigate *g* forces on urban buses equipped with a rear-facing securement system in several test scenarios to generate specific data for transit operators, regulators, bus manufacturers, persons using wheelchairs and the general traveling public.

2 METHODOLOGY

2.1 Approach

The team used CSA standards D435-02 and D436-03 as the basis for the investigation and focused on validating the crashworthiness standards prescribed in these standards. D435-02, for example, states that the strength of the securement system must be capable of withstanding 8,000 N (816 kg) in the forward direction. D436-03 specifies 17,800 N (1815 kg). This translates into 3 *g* for transit buses and 6.67 *g* for highway buses. These buses are over 7,000 kg by definition. Paratransit buses under 7,000 kg must have securement that withstands 20 *g*. The testing and evaluation involved key stakeholders, including bus manufacturers, transit operators, securement system manufacturers, and mobility aid suppliers.

2.2 Bus/Car Crashes

While certain standards, such as CSA D435-02, assume the crash loading on restrained wheelchairs in transit buses is less than 3 *g*, there was some uncertainty as to the accuracy of that value in representing real life. Little relevant crash test data is available to verify the 3 *g* value. Consequently, one objective of this project was to determine the loading on a restrained wheelchair occupant that could be expected during a bus crash.

It was decided that the crash test type best suited for this project would be the full frontal impact of a relatively large vehicle into the front end of a stationary bus. While this crash type does not represent the majority of bus collisions, it was felt that it would generate higher occupant loadings and give an indication of the upper limits of the range.

According to a report on buses involved in fatal accidents [6], 76.7% of transit buses involved in fatal collisions in the year 2000 had an empty weight between 11,340 and 13,608 kg. The U.S. Federal Highway Administration's Office of Highway Policy Information indicates that in the year 2000 the average age of the overall vehicle fleet (including heavy trucks) was between eight and nine years [7]. If the average age has remained constant since 2000, then in 2004 the average model year would be 1995 or 1996. The U.S. Environmental Protection Agency indicates the average weight of light-duty vehicles (less than 3,856 kg) for those model years is from 1,633 to 1,678 kg [8]. Using the bus and light-duty vehicle weights given above, the expected lowest mass ratio ($M_{expected}$) for transit bus crashes can be calculated (for collisions with light duty vehicles).

$$M_{expected} = \frac{m_{bus}}{m_{car}} = \frac{11340}{1678} = 6.76$$

where:

m_{bus} = lowest expected bus weight = 11,340 kg

m_{car} = average expected car weight = 1,678 kg

As a comparison, this expected mass ratio ($M_{expected}$) is much greater than the expected average ratio for all vehicles. It has been reported that a mass ratio of about 1.6:1 includes 80% to 90% of the fatal crashes in the European Union [9].

To ensure a low mass ratio in these tests, the buses were left unloaded for the crashes, while the impacting vehicles were ballasted to achieve higher weights. This ensured that the mass ratio would be lower than generally expected in real life, and as a consequence, the bus accelerations would also be higher, giving an indication of the upper limits of the expected loading.

The targeted crash speed was 48 km/h. This is the speed specified for most barrier impact tests such as those required for demonstrating compliance with Canadian Motor Vehicle Safety Standard (CMVSS) 208 [10], and CMVSS 301 [11]. This speed is also recommended for barrier impacts in the Society of Automotive Engineers (SAE) Recommended Practice J850 [12]. It was felt that, if desired, previous rigid barrier crash test data for similar bullet vehicles could be compared to the data obtained in these tests if the same speeds were used.

Since mobility devices in use range from simple mechanical wheelchairs to motorized scooters, a great number of crash tests would be necessary to fully investigate the crash loadings of occupants in the various device types. Since that approach was far beyond the scope of this project, it was decided that the floor accelerations of the crashed buses would be recorded. The floor accelerations are independent of the type of mobility device in the bus.

A total of four car-to-bus crashes were conducted for this project. The crashes were performed by IVT from April 26 to 28, 2004, at the Boundary Bay Facilities of PTEC.

2.2.1 Test Vehicles

Buses (Targets)

Four buses were donated by BC Transit for this project. BC Transit is the provincial crown agency charged with coordinating the delivery of public transportation throughout British Columbia (outside the Greater Vancouver Regional District). The buses, which were approximately 1974 vintage, were all similar models manufactured by General Motors. For this project the buses were designated T1, T2, T3 and T4 (T denotes "target"). The bus depicted in Figure 1 is typical of all four test buses.



Figure 1: Bus T2

Cars (Bullets)

PTEC donated two retired police training vehicles for this project. These vehicles, designated B1 and B2 (B denotes bullet) weighed just over 1,700 kg. These two bullet vehicles are depicted in Figures 2 and 3.



Figure 2: Car B1



Figure 3: Car B2

The Insurance Corporation of British Columbia (ICBC) also donated two cars for this project. These two cars (B3 and B4) were written off vehicles obtained from the ICBC salvage yard. The two cars weighed 1,370 kg and 1,270 kg, respectively, and are depicted in Figures 4 and 5.



Figure 4: Car B3



Figure 5: Car B4

Summary of Test Vehicle Specifications

The identification particulars of the test vehicles are listed in Table 1.

Table 1: Test vehicle identification

Project ID No.	Make	Model	Year	Serial No. / VIN	Other Identifier
T1	General Motors	T6H5308N	1974?	C077	BCT 971
T2	General Motors	T6H5308N	1974?	not found	BCT 972
T3	General Motors	T6H5308N	1974?	C082	BCT 5602
T4	General Motors	T6H5308N	1974?	C169	BCT 974
B1	Chevrolet	Caprice 4 door sedan	1989	1G1BL5173KR208969	blue
B2	Chevrolet	Caprice 4 door sedan	1990	1G1BL51E0LR142011	brown
B3	Buick	Century 4 door wagon	1985	1G4AH35X3F6434726	blue
B4	Oldsmobile	Cutlass 2 door sedan	1982	1G3AJ27XXCZ301195	blue

The weights of the test vehicles are listed in Table 2.

Table 2: Test vehicle weights (values shown in kg)

Project ID No.	Axle Weight		Vehicle Weight	Ballast / Test equipment	Crashed Weight
	Front	Rear			
T1	3,207	6,641	9,848	10	9,858
T2	3,230	6,736	9,965	80	10,046
T3	3,134	7,035	10,170	80	10,250
T4	3,243	6,972	10,215	80	10,295
B1	980	762	1,742	20	1,762
B2	930	798	1,728	20	1,748
B3	830	540	1,370	383	1,753
B4	803	463	1,266	496	1,762

2.2.2 Test Equipment and Instrumentation

Test Facilities

The crash tests were conducted using the outdoor crash test rail at the Boundary Bay facilities of PTEC. The crash test rail is approximately 100 m long. The crash test site is depicted in Figure 6.



Figure 6: Crash test rail at the Boundary Bay facilities of PTEC

A tow vehicle, using a long cable, pulled the bullet vehicles down the crash test rail until they impacted the target vehicles. The bullet vehicles were released from the guidance rail about 3 m before the impact point, so they were free to rotate during the impact event. The towline was released approximately 1 m before the impact point, so the bullet vehicles were coasting at impact.

Accelerometers

Accelerometers were attached to the floor of the bus, on the right side just behind the front wheel. This is close to the position normally occupied by a rear-facing wheelchair stall. The floor-mounted accelerometers consisted of a triaxial ± 100 g group, and a triaxial ± 10 g group.

These two groups were attached to a heavy aluminium angle, which was rigidly attached to the bus floor. The floor accelerometer installation is depicted in Figure 7.

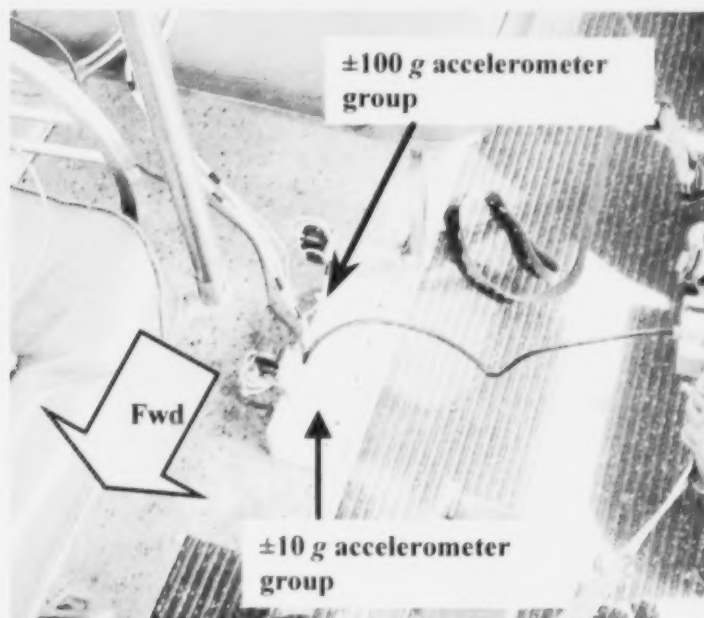


Figure 7: Floor mounted accelerometers

The floor accelerometer details are as follows:

- Floor₂ Make: Silicon Designs
Model: 2210-100
Range: ± 100 g
Frequency Response: 0 - 2000 Hz
- Floor₁ Make: Silicon Designs
Model: 2210-010
Range: ± 10 g
Frequency Response: 0 - 600 Hz

After the first crash, a set of accelerometers was installed on a bus seat for each of the remaining crashes. A ± 5 g and a ± 2 g accelerometer were installed, oriented longitudinally. These accelerometers were attached to a heavy aluminium angle, which was attached to the seat with wood screws. The seat accelerometer installation is depicted in Figure 8.

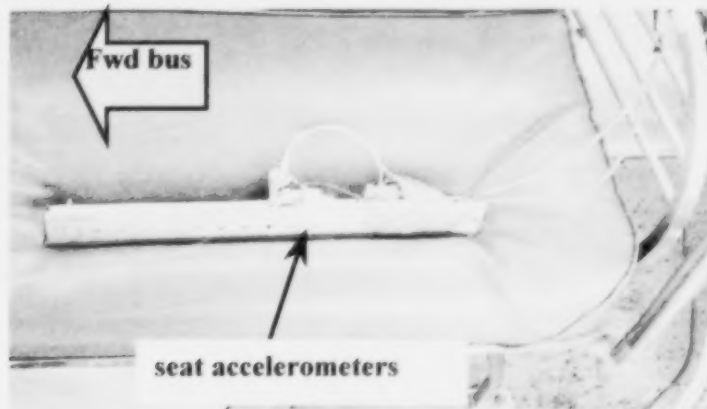


Figure 8: Seat-mounted accelerometers

The seat accelerometer details are as follows:

Seat₂ Make: Silicon Designs

Model: 2210-005

Range: ± 5 g

Frequency Response: 0 - 400 Hz

Seat₁ Make: ICSensors

Model: 3145-002

Range: ± 2 g

Frequency Response: 0 - 200 Hz

Wheelchair Restraint Loads

After the first crash, a wheelchair was placed in the buses for the remaining crashes. The wheelchair was loaded with a 68 kg bucket of sand to simulate an occupant. It was placed in the aisle of the bus, adjacent to the accelerometers. The wheelchair was restrained with cargo straps attached to a load cell. The load cell allowed the restraint loads to be measured during the bullet vehicle impact. The wheelchair and load cell installation are depicted in Figure 9.

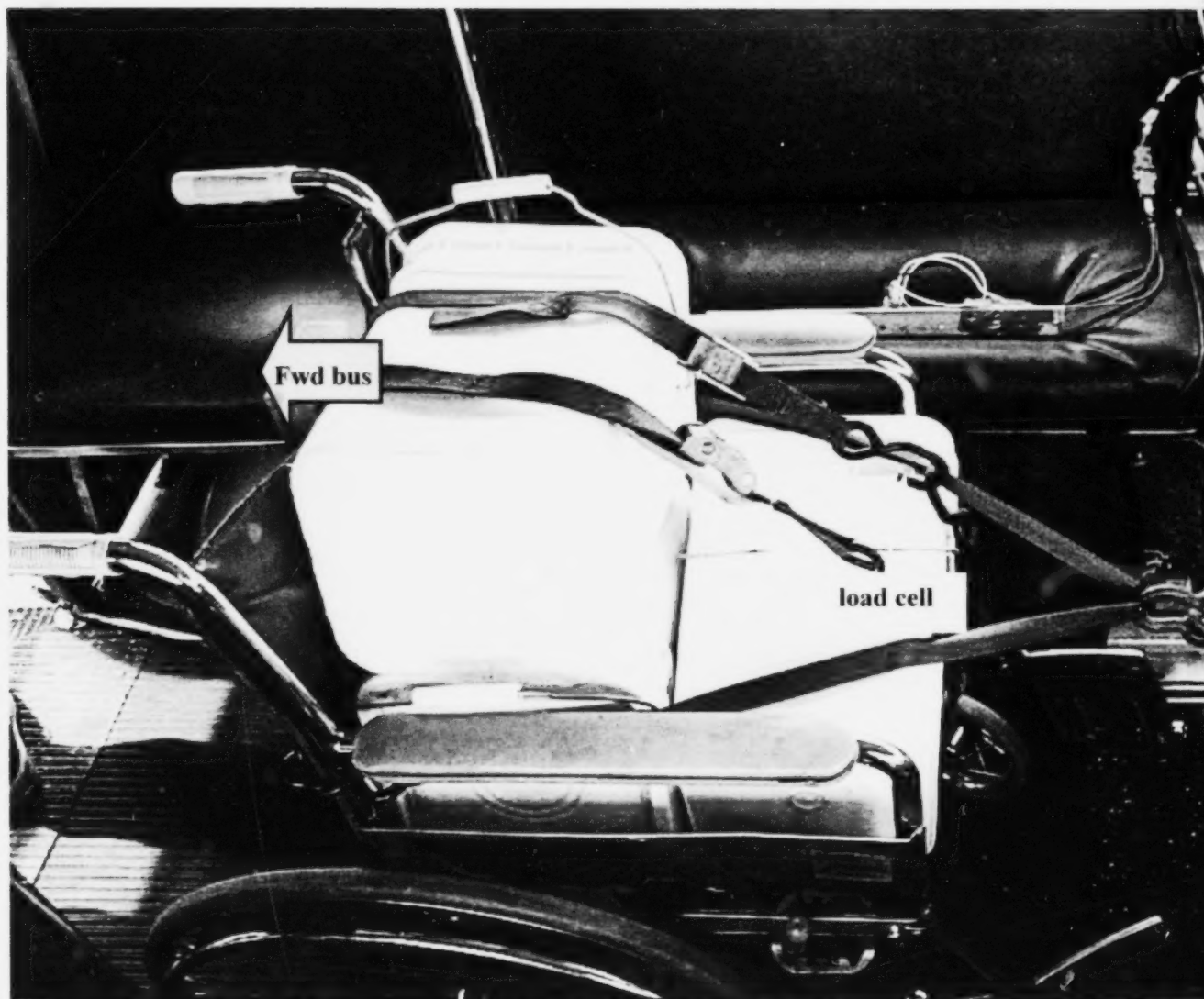


Figure 9: Wheelchair restraint load cell installation

The load cell details are as follows:

Make: Omega
Model: LCCA-2K
Range: ± 910 kg

Bullet Vehicle Contact

For each crash, a contact switch was installed on the front bumper of the target vehicle. When the bullet vehicle first contacted the target, the switch activated a flash unit, which was visible to video cameras. The switch activation signal was also recorded along with the accelerometer data.

Bullet Vehicle Speed Measurement

Retro-reflective tape was applied to the side of each bullet vehicle near the front and the back. The retro-reflective tape activated the photo switch as the bullet vehicle passed by. The switch activations were recorded using a data acquisition system. The bullet vehicle speed was calculated using the time between the photo-switch activations and the retro-reflector spacing. The retro-reflector and photo-switch installations are depicted in Figures 10 and 11.



Figure 10: Reflective tape markers on B1



Figure 11: Photo switch

Data Acquisition

All of the accelerometer, load cell, photo switch and contact switch signals were recorded using National Instruments data acquisition systems and a notebook computer. Custom software,

created with the LabVIEW programming environment was used to control the computer and data acquisition systems.

Note: No computer data was collected for Crash 2. A computer malfunction occurred shortly before the impact occurred, resulting in the loss of the impact data.

Target Snubber System

To prevent excessive rollout of the buses after the impact, they were attached to a large concrete block with a chain. The chain was left slack, which allowed the buses to roll back about 4 m before being snubbed. The snubber system is depicted in Figure 12.



Figure 12: Target snubber

Video and Photography

The crash tests were recorded using 8 mm digital video cameras operating at standard speed. Digital still cameras were used to photo-document the tests.

2.2.3 Crash Test Results

Four crash tests were conducted. Each was a full frontal crash of a bullet car into a stationary bus. The raw data indicated that the floor-mounted 10 g accelerometers saturated during the impacts, so the data from that group was disregarded.

The 100 g accelerometer data was processed per SAE Standard J211-1 [13]. The data was filtered with a 60 Hz finite impulse response filter. The processed data from the longitudinal direction accelerometer from Crash 1 is presented in Figure 13.

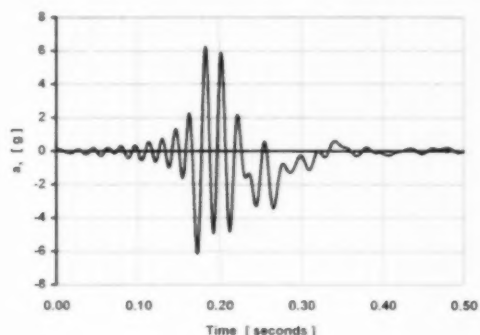


Figure 13: Crash 1 bus floor longitudinal accelerations

The floor accelerometer data exhibits ringing at about 57 Hz for about the first 100 msec (from about 0.12 seconds to 0.22 seconds) of the impact. During that time the floor accelerations range between +6 g and -6 g. A slight amount of negative acceleration is then evident in the accelerometer output (from about 0.22 seconds to 0.32 seconds). Although the longitudinal accelerations reached ± 6 g, the duration beyond ± 3 g was only about 10 msec for each excursion.

The ringing of the bus is evident in the output from all three floor-mounted accelerometers, although at slightly different frequencies. The output of the lateral (a_y) and vertical (a_z) accelerometers is depicted in Figure 14.

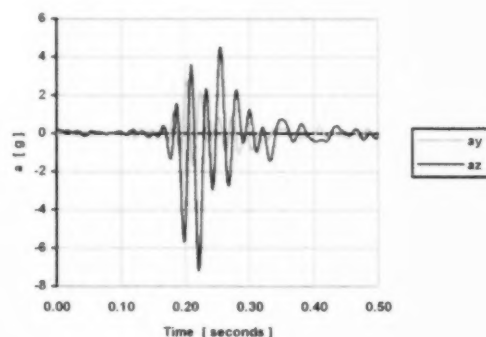


Figure 14: Crash 1 bus floor lateral (a_y) and vertical (a_z) accelerations

Impact tests were later conducted in which a large concrete block (approx. 1000 kg) was suspended from a crane and made to swing and impact the front of a bus. Bus floor acceleration data recorded during this impact exhibited the same ringing as detected during the crash tests. The presence of this phenomenon makes it difficult to detect the average rearward accelerations of the bus. Consequently, the longitudinal acceleration (a_x) data was integrated, to provide a calculated post-impact speed (V_x) for the buses. For Crash 1, the calculated post-impact speed of the bus is depicted, along with the longitudinal acceleration data (a_x) in Figure 15.

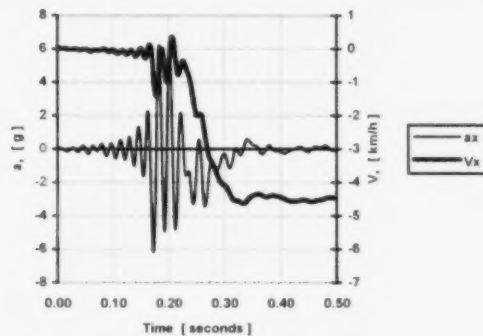


Figure 15: Crash 1 accelerations and calculated post impact bus speed

In Figure 15 the post-impact bus speed appears to be about 4.6 km/h (1.28 m/s). The average acceleration of the bus (a_x) can be obtained from the slope of the speed curve, and appears to be about $-1.5 g$.

The longitudinal accelerometer output from Crash 3 is depicted in Figure 16. Although the ringing is not as pronounced as in Crash 1, it is still evident in all three axes of accelerometer data. Consequently, the accelerometer output was again integrated to provide a calculated speed.

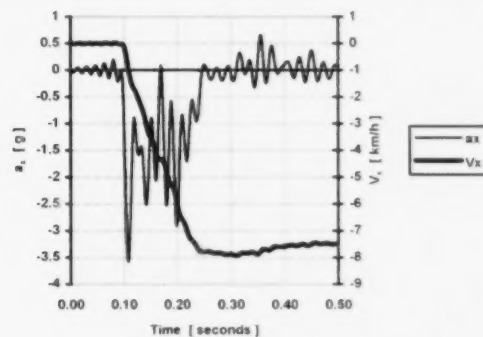


Figure 16: Crash 3 accelerations and calculated post-impact bus speed

In Crash 3 the longitudinal acceleration only exceeded $-3 g$ for a single event of about 10 msec duration. The longitudinal floor accelerometer output from Crash 4 was processed in the same fashion, and is presented in Figure 17.

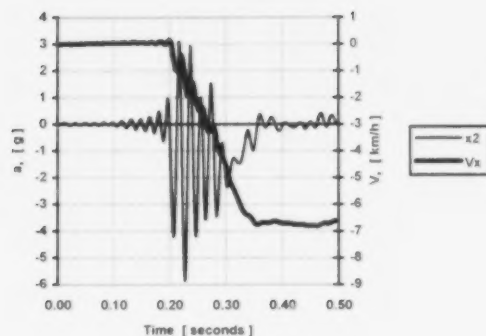


Figure 17: Crash 4 accelerations and calculated post-impact bus speed

The Crash 4 data indicates a peak of nearly 6 g was achieved. However, the ± 3 g exceedences were again of very short duration. The calculated post-impact speeds and average accelerations from Crash 1, 3 and 4 are summarized in Table 3.

Table 3: Post-impact bus speeds and average acceleration from integrated accelerometer data

Crash No.	Vehicles	Post-Impact Bus Speed [km/h]	Average Acceleration [g]
1	B4 into T4	4.6	< 3
2	B3 into T3	no data	no data
3	B1 into T1	7.93	< 3
4	B2 into T2	6.77	< 3

Although the post-impact speed of the buses was not measured directly, an analysis of the video recordings allowed the speeds to be determined. A grid painted on the ground at the crash site allowed precise measurement of the bus travel after the impact. Since the video frame rate is very stable, it provides a good time base for the speeds calculations. The post-impact speeds from video are listed in Table 4.

Table 4: Post-impact bus speeds from video analysis

Crash No.	Vehicles	Post Impact Bus Speed [km/h]
1	B4 into T4	no data
2	B3 into T3	7.05
3	B1 into T1	7.32
4	B2 into T2	7.75

Of the two methods of calculating the post-impact bus speed (integrated accelerometer data and video analysis) the video analysis is the more consistent.

A review of the video recording confirmed that the buses were stationary for the initial part of the impact, while the front end of the car crumpled. During that time period, the impact closely resembled a rigid barrier impact test, and that is when the ringing is most evident. When the maximum crush on the car was achieved, the bus began to back up. Excerpts from the video of Crash 2 are depicted in Figure 18.



Figure 18: Frame 1 and frame 5 from Crash 3 video

The two photos in Figure 18 are separated by about 130 msec. In the first frame the bullet vehicle has nearly contacted the target. In the next frame (frame 5) the bus has just begun to move backward. The bus remains nearly motionless during the time while the car deforms. In frame 5, the car has stopped, without rebounding.

As indicated in section 2.2.2, a wheelchair with 68 kg of ballast was secured in the aisle of the buses in Crash 2, Crash 3 and Crash 4. The wheelchair securing strap was attached to a load cell, the output of which was recorded along with the bus floor accelerations. In addition, two longitudinally oriented accelerometers were attached to a bus seat, close to the wheelchair

location. Load cell output data was available from Crash 3 and Crash 4 only. The output from Crash 3 is depicted in Figure 19.

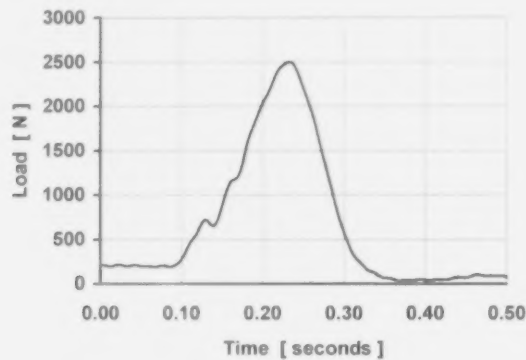


Figure 19: Crash 3 wheelchair restraint load

From Figure 19 it can be seen that the wheelchair restraint load reached about 250 kg following the impact. Correcting the belt angle would bring the g force calculation below 3 g. Nearly identical results were obtained from Crash 4. The seat accelerometer data from Crash 3 and Crash 4 was analyzed. The output from Crash 3 is depicted in Figure 20.

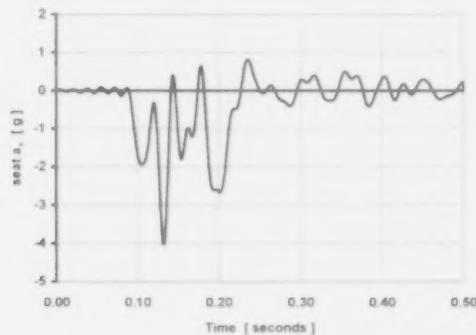


Figure 20: Crash 3 seat longitudinal accelerations

In Figure 20 the seat accelerations can be seen to peak at about 4 g. However, the duration beyond -3 g is again about 10 msec.

Crash 1

The vehicles used in Crash 1 were bus T4 and car B4. Pre-crash alignment of these vehicles is depicted in Figure 21.



Figure 21: T4 and B4

Vehicle B4 was loaded with ballast to achieve a weight similar to vehicles B1 and B2. The tested weight of B4, including test equipment and ballast, was 1,762 kg, while the weight of bus T4, including instrumentation, was 10,225 kg. This yielded a mass ratio of 5.80:1. In this test the impact speed was 53.1 km/h. The damage to T4 is depicted in Figure 22.



Figure 22: Result of Crash 1 (T4)

The damage to B4 is depicted in Figure 23.



Figure 23: Result of Crash 1 (B4)

The post-impact fit of the vehicles is demonstrated in Figure 24.



Figure 24: Result of Crash 1 (T4 and B4)

Crash 2

The vehicles used in Crash 2 were bus T3 and car B3. Pre-crash alignment of these vehicles is depicted in Figure 25.

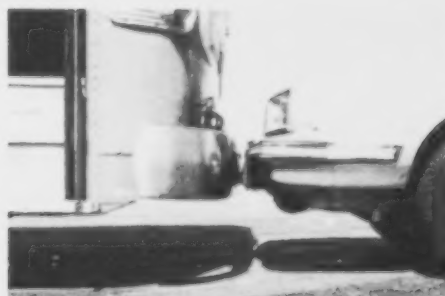


Figure 25: T3 and B3

Vehicle B3 was loaded with ballast to achieve a weight similar to vehicles B1 and B2. The tested weight of B3, including test equipment and ballast, was 1,753 kg, while the weight of bus T3, including instrumentation, wheelchair and ballast, was 10,250 kg. This yielded a mass ratio of 5.85:1. In this test the impact speed was approximately 48 km/h. The damage to T3 is depicted in Figure 26.



Figure 26: Result of Crash 2 (T3)

The damage to B3 is depicted in Figure 27.



Figure 27: Result of Crash 2 (B3)

The vehicles are shown, shortly after impact, in Figure 28.



Figure 28: Result of Crash 2 (T3 and B3)

Crash 3

The vehicles used in Crash 3 were bus T1 and car B1. Pre-crash alignment of these vehicles is depicted in Figure 29.



Figure 29: T1 and B1

The tested weight of B1, including test equipment, was 1,762 kg, while the weight of bus T1, including instrumentation, wheelchair and ballast, was 9,928 kg. This yielded a mass ratio of

5.75:1. In this test the impact speed was approximately 49.9 km/h. The damage to T1 is depicted in Figure 30.



Figure 30: Result of Crash 3 (T1)

The damage to B1 is depicted in Figure 31.



Figure 31: Result of Crash 3 (B1)

The post-impact fit of the vehicles is demonstrated in Figure 32.



Figure 32: Result of Crash 3 (T1 and B1)

Crash 4

The vehicles used in Crash 4 were bus T2 and car B2. Pre-crash alignment of these vehicles is depicted in Figure 33.



Figure 33: T2 and B2

The tested weight of B2, including test equipment, was 1,748 kg, while the weight of bus T2, including instrumentation, wheelchair and ballast, was 10,046 kg. This yielded a mass ratio of 5.63:1. In this test the impact speed was approximately 48.6 km/h. The damage to T2 is depicted in Figure 34.



Figure 34: Result of Crash 4 (T2)

The damage to B2 is depicted in Figure 35.



Figure 35: Result of Crash 4 (B2)

The post-impact fit of the vehicles is demonstrated in Figure 36.



Figure 36: Result of Crash 4 (T2 and B2)

Crash Test Summary

The crash test data is summarized in Table 5. In that table the post-impact speed obtained through video analysis is used, except for crash 1, which did not have suitable video available. For Crash 1 the speed calculated by integrating accelerometer data is used.

Table 5: Crash test data summary

Crash No.	Vehicles	Impact Speed [km/h]	Post-Impact Bus Speed [km/h]	Average Acceleration [g]	Vehicle Mass [kg]		Mass Ratio
					Bus	Car	
1	B4 into T4	53.09	4.6 (from a_x)	< 3	10,225	1,762	5.80
2	B3 into T3	≈ 48	7.05	no data	10,250	1,753	5.85
3	B1 into T1	49.90	7.32	< 3	9,928	1,762	5.63
4	B2 into T2	48.57	7.75	< 3	10,046	1,748	5.75

2.3 Extreme Manoeuvring Tests

For this series of tests, four different buses were operated on a pre-set test course, designed to duplicate extreme service conditions. An anthropomorphic test device (dummy) was placed in various mobility aids, which were situated in the rear-facing wheelchair stall of the buses being tested. The aim of the tests was to observe the reactions of the dummy and the mobility aids, and to determine the suitability of the rear-facing stalls.

IVT performed the tests on the course established at the Boundary Bay facilities of PTEC. IVT recorded bus performance data, consisting of vehicle speeds and accelerations, as well as video recordings of the dummy in the various mobility aids.

2.3.1 Wheelchairs

Five different wheelchairs were used in the extreme manoeuvring testing. The chairs were labelled A, B, C, D, and E.

Wheelchair A was a manual, foldable wheelchair. This chair is depicted in Figure 37.

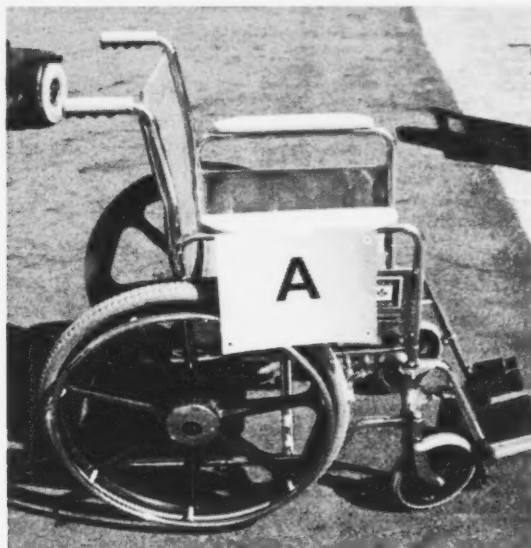


Figure 37: Wheelchair A

Wheelchair B was a powered three-wheeled scooter. This chair is depicted in Figure 38.



Figure 38: Wheelchair B

Wheelchair C was a powered wheelchair. This chair is depicted in Figure 39.



Figure 39: Wheelchair C

Wheelchair D was a powered four-wheeled scooter. This chair is depicted in Figure 40.



Figure 40: Wheelchair D

Wheelchair E was a powered wheelchair. This chair is depicted in Figure 41.



Figure 41: Wheelchair E

2.3.2 Buses

Four buses of different types were provided for the tests by BC Transit. Each was equipped with a rear-facing wheelchair stall, and each stall was equipped with a single restraint strap. All except the double-decker had an aisle stanchion to limit lateral movement of the mobility device. In the tests reported here, the stalls in these three buses were reconfigured to have either a stanchion or a belt only.

9 m Dennis Dart

The first bus tested was a 9 m Dennis Dart bus. This was a wheelchair accessible bus with a rear-facing wheelchair stall located on the right side of the bus near the front. The bus was equipped with air suspension. It had a powered deployed wheelchair ramp and could dump the air from the front suspension, allowing the bus to drop approximately 76 mm. The bus is depicted in Figure 42.



Figure 42: 9 m Dennis Dart bus

The wheelchair stall is depicted in Figure 43.



Figure 43: Dummy in wheelchair A in rear-facing stall in 9 m Dennis Dart bus

10.5 m Dennis Dart

The second bus tested was a 10.5 m Dennis Dart bus. This was a wheelchair accessible bus with a rear-facing wheelchair stall located on the left side of the bus behind the driver. The bus was equipped with air suspension. It had a powered deployed wheelchair ramp and could dump the air from the front suspension, allowing the bus to drop approximately 76 mm. The bus is depicted in Figure 44.



Figure 44: 10.5 m Dennis Dart bus

The wheelchair stall is depicted in Figure 45.



Figure 45: Dummy in wheelchair B in rear-facing stall in 10.5 m Dennis Dart bus

12 m New Flyer

The third bus tested was a 12 m New Flyer bus. This was a wheelchair accessible bus with a rear-facing wheelchair stall located on the right side of the bus near the front. The bus was equipped with air suspension. It had a powered deployed wheelchair ramp and could dump the air from the front suspension, allowing the bus to drop approximately 76 mm. The bus is depicted in Figure 46.



Figure 46: 12 m New Flyer bus



Figure 47: Dummy in wheelchair B in rear-facing stall in 12 m New Flyer Bus

Double-Decker Dennis Trident

The fourth bus tested was a 12 m double-decker Dennis Trident bus. This was a wheelchair accessible bus with a rear-facing wheelchair stall located on the left side of the bus behind the upper level stairway. The bus was equipped with air suspension. It had a powered deployed wheelchair ramp and could dump the air from the front suspension, allowing the bus to drop approximately 76 mm. The bus is depicted in Figure 48.



Figure 48: Double-decker Dennis Trident bus



**Figure 49: Dummy in wheelchair A
in rear-facing stall in double-decker bus**

2.3.3 Test Equipment and Instrumentation

For these tests the buses were equipped with a number of sensors and instruments. Most importantly, a triaxial accelerometer group was attached to the floor of the bus near the wheelchair stall. A yaw rate sensor was also attached at the same location. The instrumentation package is depicted in Figure 50.

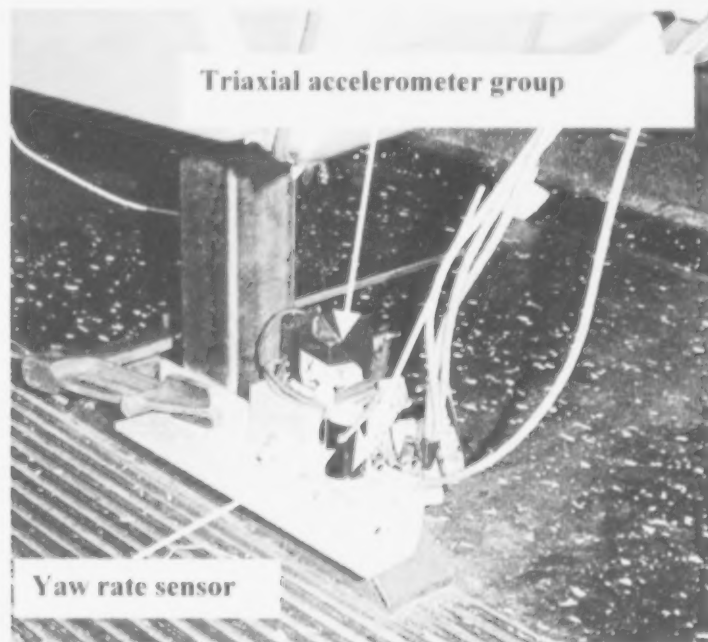


Figure 50: Accelerometer group and yaw rate sensor

Ultrasonic height sensors were attached to the front bumper of the bus. The sensors enabled the roll angle of the vehicle to be measured during manoeuvring. Also attached to the front bumper was a radar speed sensor. The height and speed sensors are depicted in Figure 51.

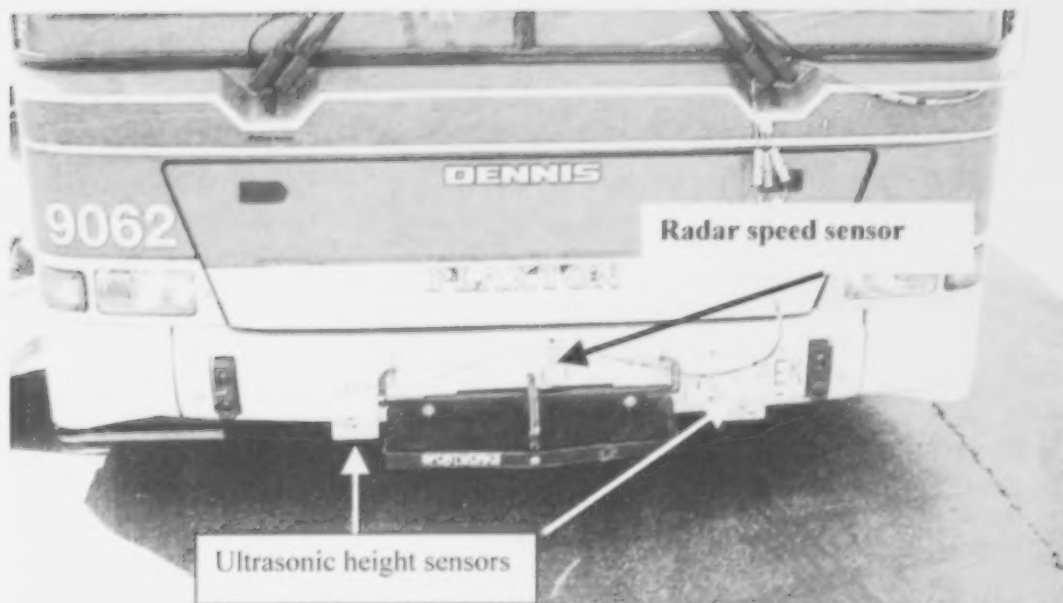


Figure 51: Speed and height sensors attached to the front bumper of a bus

The following equipment was used during the testing.

Speed Sensor

In addition to the vehicle speedometer, the vehicle speed was measured with a radar speed sensor.

Make: GMH Engineering
 Model: Delta Speed Sensor DRS1000
 Range: 0-480 km/h

This sensor outputs a TTL signal at a rate of 131.5 Hz/km/h. The speed sensor output was converted to a proportional analog signal with a frequency-to-voltage converter (f/V):

Make: Red Lion Controls
 Model: IFMA Frequency to Analog Converter
 Range: 1-25 kHz

The f/V output (speed data) was recorded by the onboard computer during the testing.

Accelerometers

Vehicle accelerations were measured during the testing using a triaxial accelerometer group.

Make: ICS Sensors
 Model: 3145-002
 Range: $\pm 2 g$

In addition, an accelerometer was used to provide the test vehicle driver with an indication of the accelerations:

Make: Valentine Research
Model: G-Analyst
Range: ± 2 g

Yaw Rate Sensor

A solid-state rotational rate sensor was used to measure the vehicle yaw (rotation about the vertical axis).

Make: CFX Technologies
Model: UCG-1
Range: $\pm 50^\circ/\text{sec}$

Height Sensor

Two ultrasonic distance sensors were mounted on the front bumper of each bus. The output of these sensors was used to calculate the roll angle of the buses.

Make: EDP SonaSwitch
Model: Mini-A
Range: adjustable 3 m

Portable Computer and Data Acquisition System

A notebook computer using an Intel P650 processor and operating under Windows 98 was used to collect test data. A National Instruments analog-to-digital (A/D) board was used to convert speed, acceleration, yaw rate and height sensor signals to digital format for storage in the notebook computer. LabVIEW software was used on the computer to control the A/D board and process the data.

2.3.4 Video and Photography

Testing was documented using handheld digital video cameras and a digital still camera. Vehicle information was recorded with a digital still camera.

2.3.5 Anthropomorphic Test Device

An anthropomorphic test device (dummy) was used to simulate a wheelchair occupant for these tests. The dummy was on loan from the University of Michigan Transportation Research Institute. The dummy was a 50th percentile male Hybrid II, which has a mass of about 78 kg. The dummy is depicted in Figure 52.



Figure 52: Hybrid II dummy in wheelchair B

2.3.6 Test Course

The test course was laid out at PTEC's Boundary Bay facilities in Delta, B.C. The course occupied a 60 m x 600 m segment of the facility. The course surface was brushed concrete runway, which has a friction coefficient of about 0.9 when test dry per ASTM Standard E274 [14].

The test course consisted of a left-hand turn and a right-hand turn located at opposite ends of the course. The distance between the two turns was approximately 425 m. The radius of the turns was 23.165 m, which was as large as the runway width could accommodate. The lateral accelerations were to be limited to approximately 0.3 g, which was well below the expected rollover threshold of any of the test vehicles. These conditions limited the cornering speed to

about 30 km/h. The right-hand turn exit had a radius of 20.726 m and the left-hand turn exit had a radius of 25.603 m. A double lane change manoeuvre was located between the two turns. The lane change manoeuvre was set up as per the requirements of ISO 14791 [15]. The lane change segment would generate 0.3 g lateral acceleration at 50 km/h. Per ISO 14791 the lane change frequency was set to 0.4 Hz, which gives a 2.5 second lane change duration. That frequency is sufficient to allow the test vehicle to achieve considerable roll angle.

The double lane change was created by setting up two opposite lane changes, one right after the other. The double lane change was 69.44 m long, with a 2.927 m offset. The double lane change took approximately 5 seconds to negotiate.

The spacing between the end turns was sufficiently large to allow all of the vehicles to achieve 50 km/h before entering the lane change manoeuvre. The test course is depicted in Figure 53.

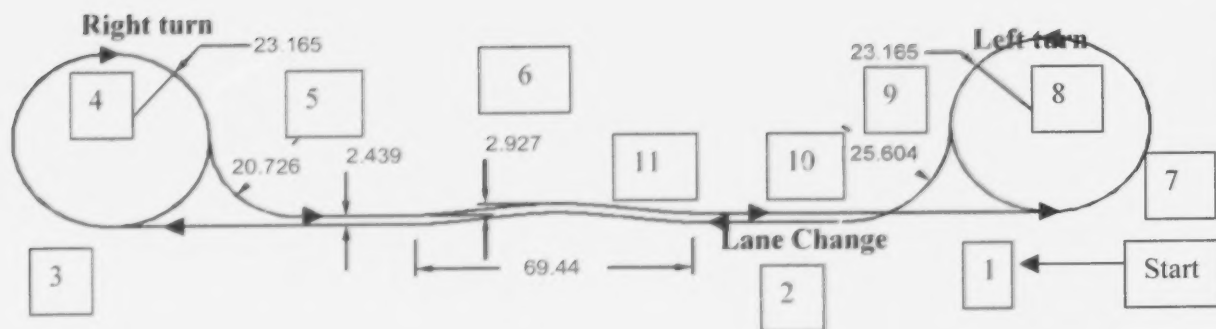


Figure 53: Extreme manoeuvring test circuit layout (not to scale; dimensions in m)

Boxed numbers indicate critical measuring points on the test track.

1. Acceleration from start to 50 km/h
2. ISO lane change to left
3. Right turn
4. Brake in right turn
5. Right to left turn
6. ISO lane change to right
7. Left turn
8. Brake in left turn
9. Left to right turn
10. Acceleration to 50 km/h
11. Brake on straight

2.3.7 Extreme Manoeuvring Test Results

A total of 36 tests were performed with the four buses. The results of a single test with the 9 m Dennis Dart bus are presented here as an example. The speed history is depicted in Figure 54. In that figure, it can be seen that the vehicle negotiated the lane change manoeuvre at approximately 50 km/h, while the steady-state turns were maintained at about 25 km/h.

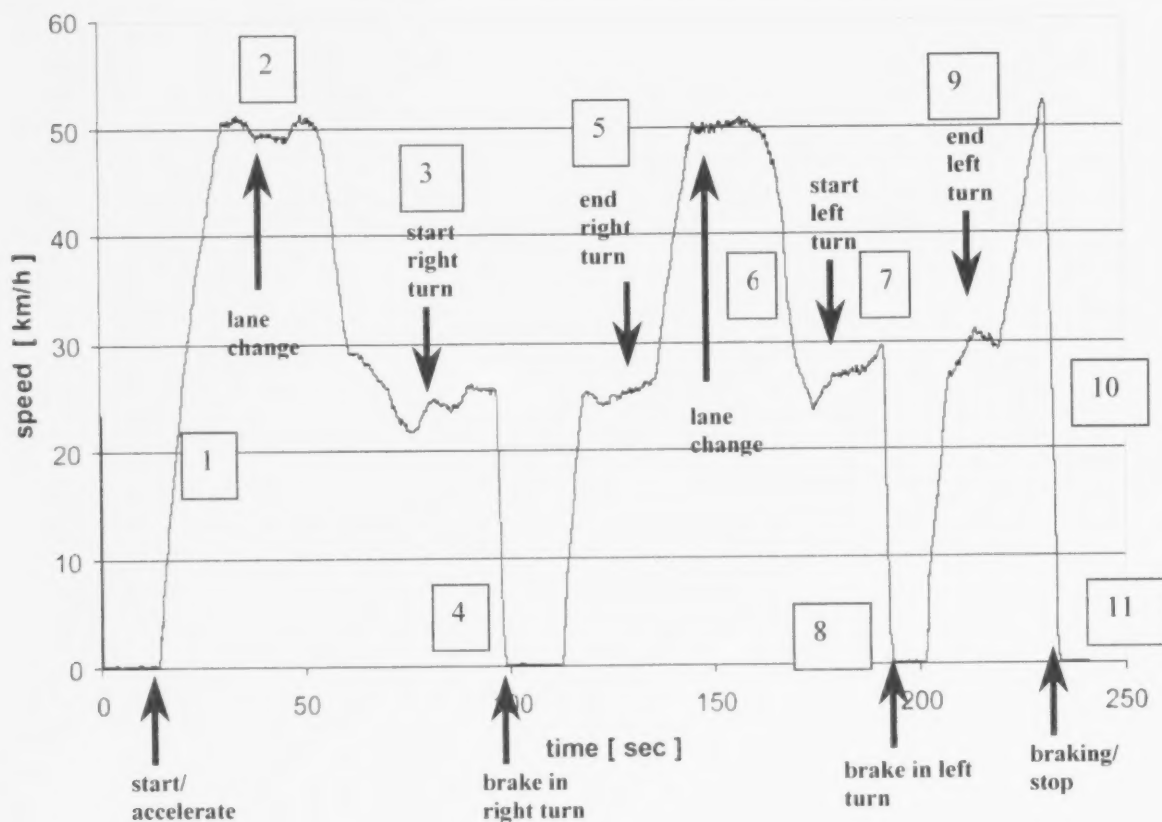


Figure 54: Vehicle speed, 9 m Dennis Dart bus

The longitudinal acceleration history is depicted in Figure 55. In that figure it can be seen that the bus was able to achieve approximately -0.5 g during braking, and slightly over 0.1 g maximum acceleration.

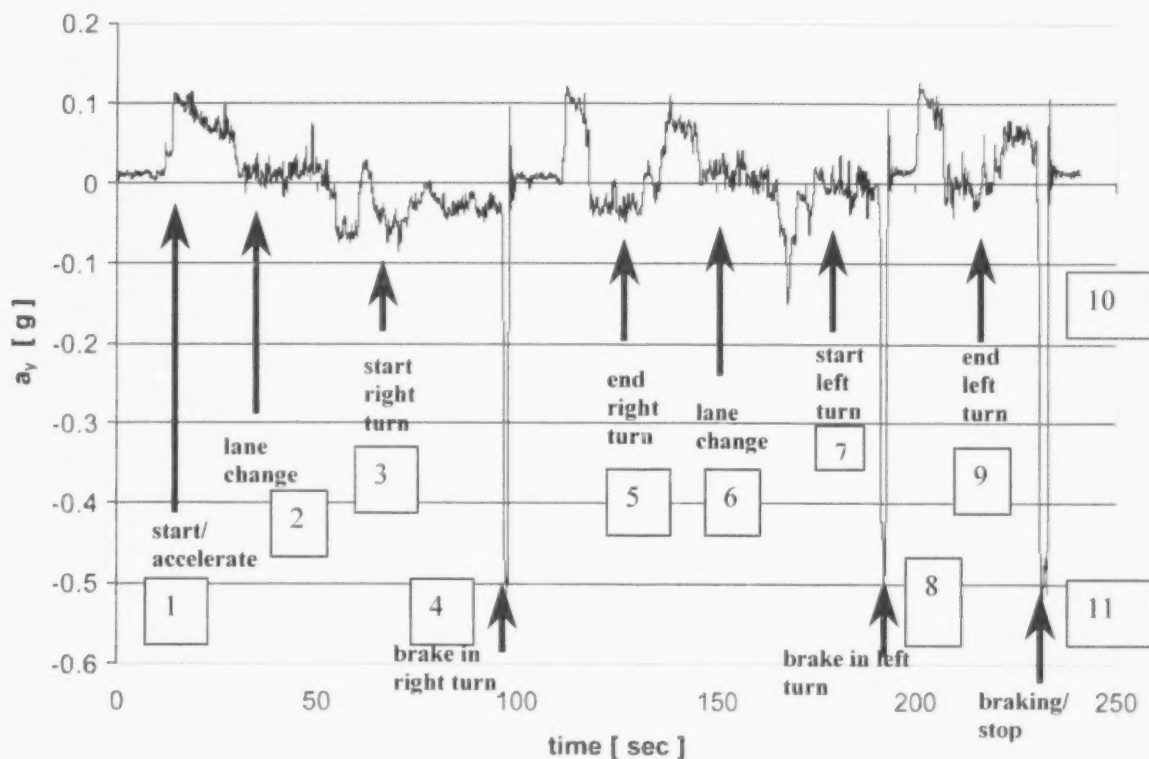


Figure 55: Longitudinal accelerations, 9 m Dennis Dart bus

The lateral acceleration history is depicted in Figure 56. (The accelerometer data in that figure is offset by approximately 0.02 g.) It can be seen that the lane change manoeuvre generated approximately 0.2 g laterally. The steady state-turns were made at about 0.2 g.

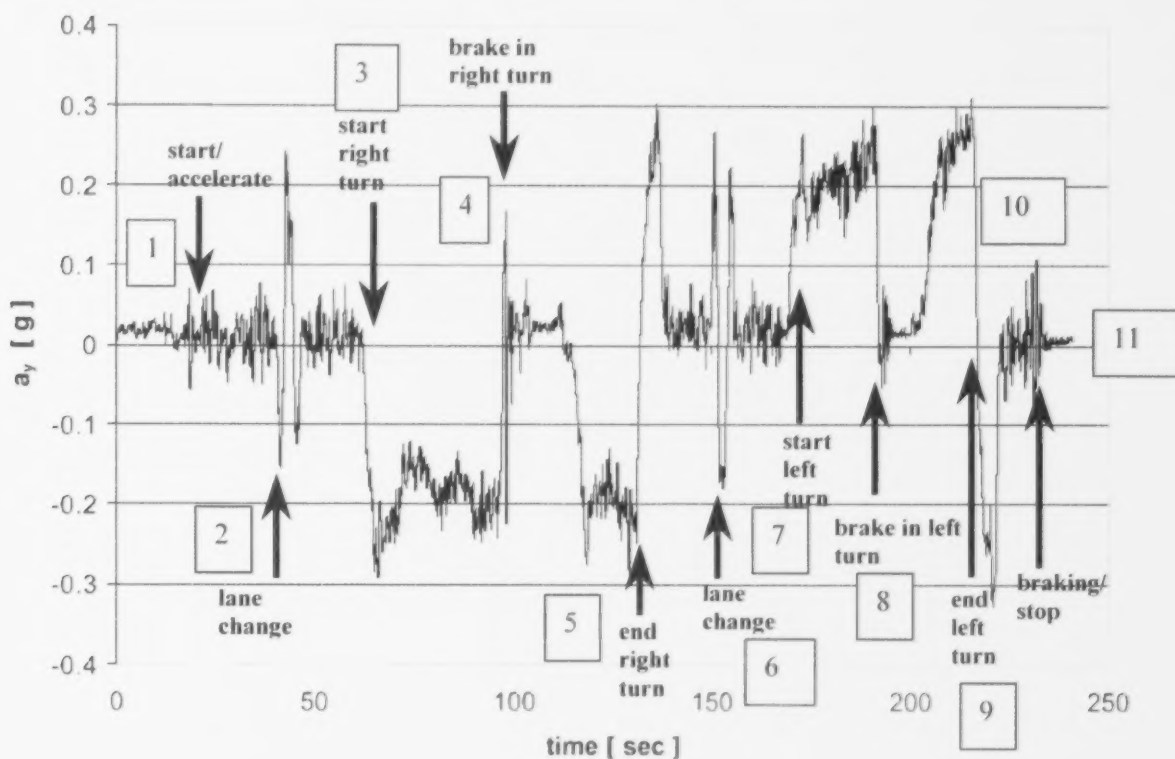


Figure 56: Lateral accelerations, 9 m Dennis Dart bus

The aim of these tests was to observe the reactions of a rear-facing wheelchair stall occupant under any expected combination of lateral and longitudinal accelerations. The combinations of lateral and longitudinal accelerations are depicted in Figure 57. That figure depicts a friction circle for the bus tested. Figure 57 indicates that nearly all combinations of longitudinal and lateral accelerations were achieved as the test course was negotiated.

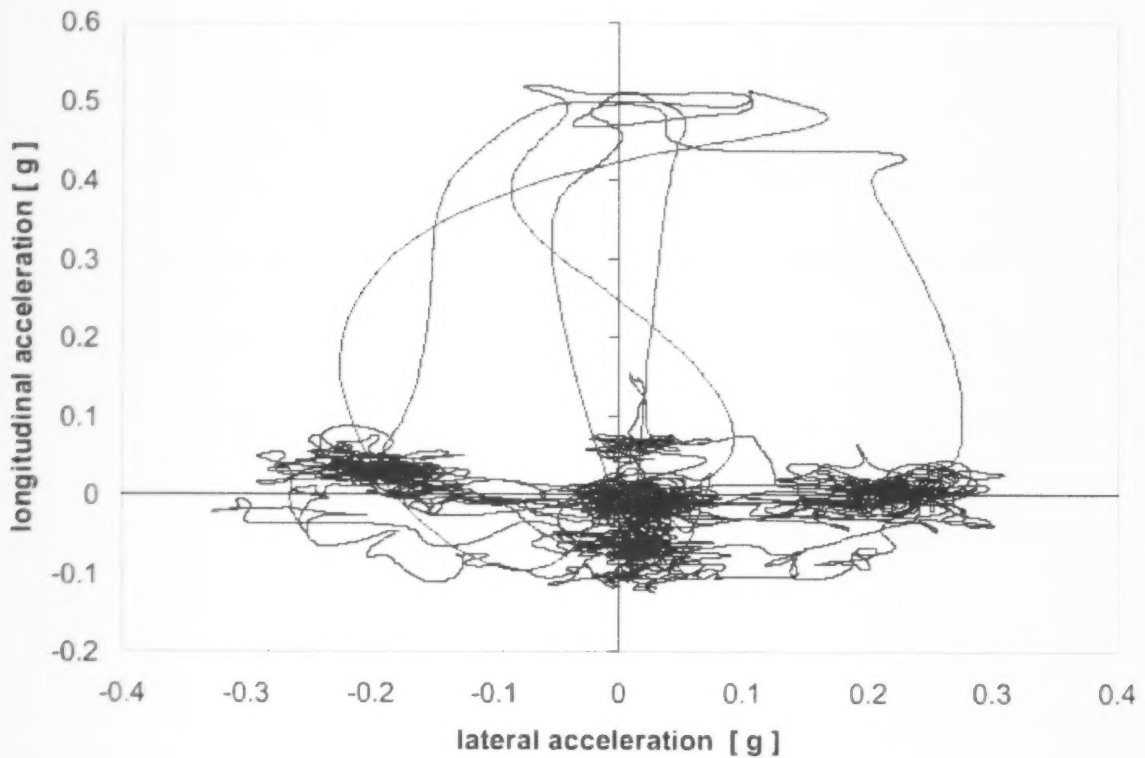


Figure 57: Friction circle for 9 m Dennis Dart bus

The test course was repeated as closely as possible for each combination of bus and mobility aid. As a result similar results to those presented above were obtained for all of the buses tested.

As indicated in section 2.3.3, the buses were equipped with height sensors on the front bumper. This equipment allowed the roll angle of the bus to be calculated. In Figure 58, the roll angle of the bus is plotted against the lateral acceleration. A regression analysis of the result is also shown in Figure 58. The regression line is the roll stiffness of the bus, in degrees per g of lateral acceleration. For the 9 m long Dennis Dart bus the roll stiffness was found to be 7.8° per g .

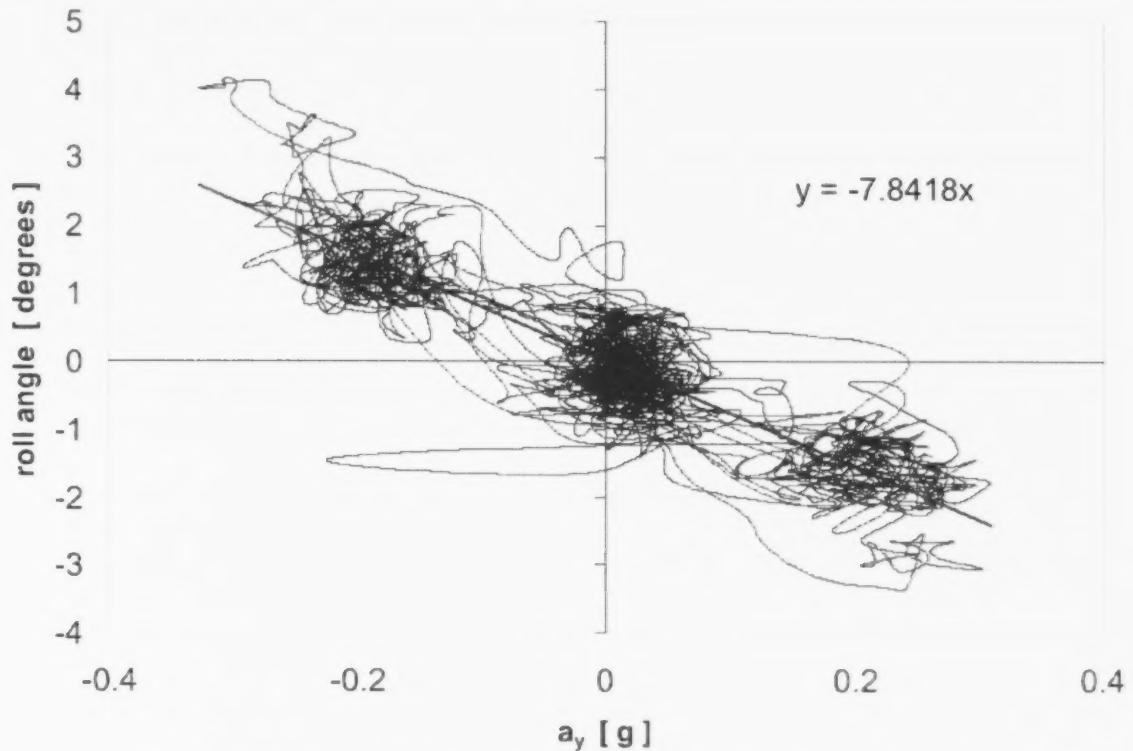


Figure 58: Roll angle vs. lateral acceleration for 9 m Dennis Dart bus

The roll angle contributes to the effect of the lateral accelerations, and increases the tendency of the wheelchairs and occupants to fall over. However, lateral accelerations only reached a maximum slightly higher than $0.3 g$, so in no cases would the roll angle reach much beyond 3° . The roll stiffness for the four buses tested is listed in Table 6.

Table 6: Roll stiffness of test buses

Bus	Roll Stiffness [deg / g]
9 m Dennis Dart	7.8
10.5 m Dennis Dart	9.2
12 m New Flyer	8.5
12 m Trident Double Decker	6.6

It is interesting to note that, in spite of having the highest Centre of Gravity (CG) height, the Trident Double Decker had the highest roll stiffness.

Table 7: Mobility aids restraint configurations

Bus type	Wheelchair types				
	A: manual	B: 3-wheeled scooter	C: power	D: 4-wheeled scooter	E: electric
9 m Dennis Dart with stanchion	√	√	√	√	√
9 m Dennis Dart with cross belt	√	√	√	√	√
10.5 m Dennis with stanchion	√	√			√
10.5 m Dennis with cross belt	√	√			√
12 m New Flyer with stanchion	√	√	√	√	
12 m New Flyer with cross belt		√			
Double-decker with cross belt	√	√	√	√	

A cursory review of videotape recorded during these tests showed little movement of the dummy or mobility aids except for the three-wheeled scooter, which tipped into the aisle in both the continuous turn and sudden reverse turn manoeuvres. It remained upright during the lane change manoeuvres.

The acceleration of the buses was too low to cause any significant movement of the dummy or mobility aids. However, the hard braking manoeuvres caused all of the mobility aids and the dummy to slide rearward into the stall backrest. Several mobility aids slid sideways a small

amount in the continuous turn but were contained by the vertical stanchion. The restraint strap was sufficient to keep each of them in the stall during all manoeuvres.

According to the test results there seems to be very little difference in the performance of the buses as far as their size and weight are concerned. For instance, lane change manoeuvres resulted in 0.2 to 0.25 g for all buses. This indicated that the 9 m Dennis Dart does not generate bigger lateral accelerations than the heavy 12 m double decker. For the passenger, this means that there is no significant difference in risk in using a small or large transit bus. That the smallest 9 m Dennis Dart performed equivalent to the largest 12 m double decker indicates that CSA Standard D435-02 would be equally valid for a wide range of buses.

2.3.8 Observations

During the extreme manoeuvring testing, the movements of the wheelchairs/scooters and the dummy were recorded by two video cameras, one facing the front of the dummy to record its movements, and the other positioned perpendicular to record the movements of the chair. The tapes were then evaluated and the results are shown in Tables 7 through 19. The test track schematic in Figure 59 shows 11 critical points in the manoeuvre, which are shown in the tables. They indicate the relevant movements of the wheelchair and the dummy.

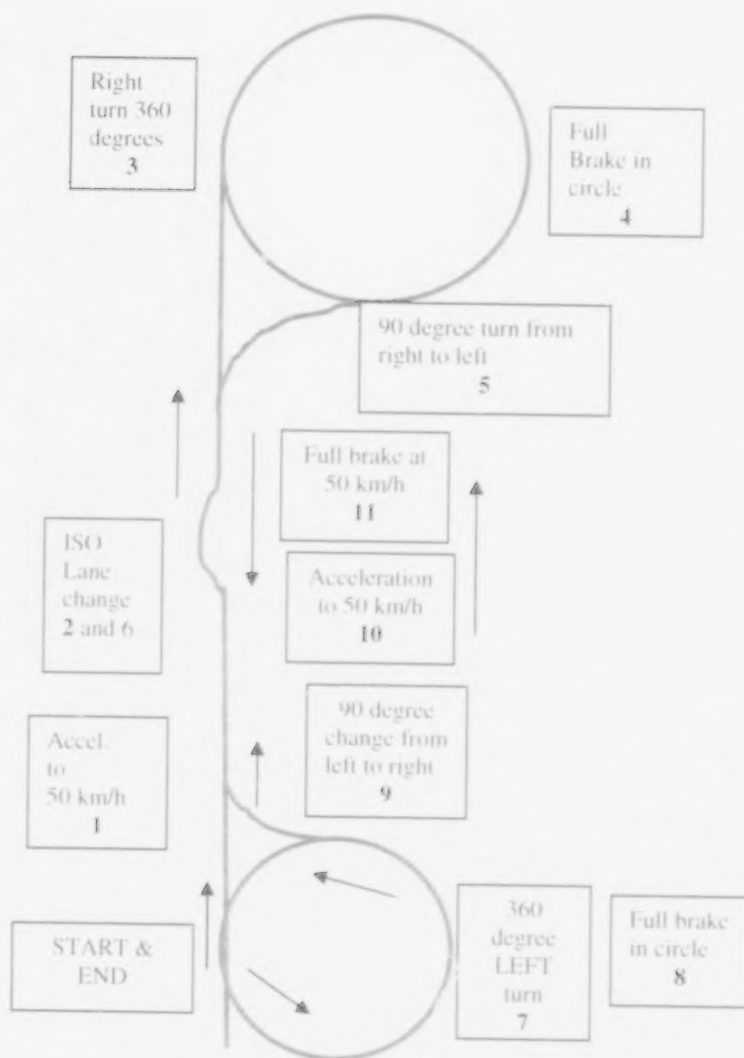


Figure 59: Test track layout for extreme manoeuvring testing June 2004 at Boundary Bay Airport (numbers indicate critical observation points)

Table 8: 9 m Dennis Dart bus, manual wheelchair with aisle stanchion or cross belt¹

	Critical points on test track										
	1 Accel.	2 Lane change LEFT	3 RIGHT turn	4 Brake in right turn	5 Right to left turn	6 Lane change RIGHT	7 LEFT turn	8 Brake in left turn	9 Left to right turn	10 Accel. straight	11 Brake on straight
Wheelchair Type A Manual Aisle stanchion	Stable	Moves very slightly sideways	Front moves to aisle about 8 cm	Front wheels lift, chair slides back	Stable	Stable	Stable	Front wheels lift, chair slides back	Moves to aisle	Stable	Front wheels lift, chair slides back
Dummy	Stable	Sways very slightly sideways	Stable	Head contacts backrest and rebounds	Stable	Stable	Stable	Head contacts backrest and rebounds	Sways left and right	Stable	Head contacts backrest and rebounds
Wheelchair Type A Manual Cross belt	Stable	Stable	Stable	Front wheels lift	Stable	Stable	Front moves to wall	Front lifts	Stable	Stable	Front wheels lift
Dummy	Stable	Stable	Stable	Head contacts backrest and rebounds	Stable	Stable	Stable	Head contacts backrest and rebounds	Stable	Stable	Head contacts backrest and rebounds

Conditions (Tables 8 – 12):

9 m Dennis Dart low-floor bus

Rear-facing system located at curbside

Distance from passenger's back to backrest about 25 cm

Backrest equipped with jump seat

Wheelchairs and scooters tested with brakes applied

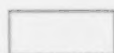
In the tests, the dummy and the wheelchair did not experience dangerous movements. Both remained stable in all situations. The application of a cross belt did not seem to improve the ride quality.

¹ **Aisle stanchion:** a fixed post in the bus at the aisle side of the wheelchair position to prevent the wheelchair from tipping or rolling into the aisle.

Cross belt: a belt attached with one end at the backrest structure at about seat height and the other diagonally attached on the bus wall in front of the wheelchair to prevent three-wheeled scooters from tipping into the aisle.

Table 9: 9 m Dennis Dart bus, three-wheeled scooter with stanchion or cross belt

Critical points on test track											
	1. Accel.	2 Lane change LEFT	3 RIGHT turn	4 Brake in right turn	5 Right to left turn	6 Lane change RIGHT	7 LEFT turn	8 Brake in left turn	9 Left to right turn	10 Accel. straight	11 Brake on straight
Wheelchair Type B three- wheeled scooter Aisle stanchion	Stable, seat sways	Stable, seat sways	Stable, seat sways	Rolls back	Stable, seat sways	Stable, seat sways	Front moves to wall	Rolls back	Moves 30 cm into aisle	Stable, seat sways	Front wheel lifts
Dummy	Stable, seat sways	Leans slightly left and right	Upper body tips into aisle	Upper body misses backrest	Leans left and right	Sways slightly left and right	Contact with bus wall	Head contact backrest and rebounds	Leans into aisle	Stable, seat sways	Head contact backrest and rebounds
Wheelchair Type B three- wheeled scooter Cross belt	Stable, seat sways	Stable, seat sways	Stable, seat sways	Stable, seat sways	Front moves to wall	Stable, seat sways	Front contacts wall	Roll back about 8 cm	Stable, seat sways	Stable, seat sways	Roll back about 8 cm
Dummy	Stable, seat sways	Sways slightly left and right	Leans strongly to aisle	Head contacts backrest and rebounds	Leans left and right	Sways slightly left and right	Leans strongly to wall	Head contacts backrest and rebounds	Leans left and right	Stable, seat sways	Head contacts backrest and rebounds



Areas of concern

The three-wheeled scooter's power platform remained very stable throughout the test, whereas the seat, mounted on one column, swayed constantly and seemed to assist in the dummy's instability. In one turn, the upper body of the dummy was dangerously tipped over into the aisle, as a result of the momentum gathered by constant swaying of the seat. The cross belt helped to restrict the scooter's platform marginally, but could not improve the seat's swaying. The distance between the passenger's back and the backrest was about 30 cm due to the fact that the battery pack could not fit under the backrest.

Table 10: 9 m Dennis Dart bus, power wheelchair with aisle stanchion or cross belt

	Critical points on test track										
	1. Accel.	2 Lane change LEFT	3 RIGHT turn	4 Brake in right turn	5 Right to left turn	6 Lane change RIGHT	7 LEFT turn	8 Brake in left turn	9 Left to right turn	10 Accel. straight	11 Brake on straight
Wheelchair Type C Power chair Aisle stanchion	Stable	Stable	Stable	Stable	Front moves to wall	Stable	Front contact wall	Rolls back 8 cm	Front moves to aisle	Stable	Rolls back 8 cm
Dummy	Stable	Stable	Stable	No contact with backrest or rebound	Arm contacts wall	Stable	Arm contacts wall	No contact with backrest or rebound	Stable	Stable	No contact with backrest or rebound
Wheelchair Type C Power chair Cross belt	Stable	Stable	Stable	Stable	Front moves to wall	Stable	Front moves to wall	Stable	Stable	Stable	Stable
Dummy	Stable	Very slight leaning left and right	Very slight leaning left and right	No contact with backrest or rebound	Arm contacts wall	Very slight leaning left and right	Arm contacts wall	No contact with backrest or rebound	Stable	Stable	No contact with backrest or rebound

Tests showed that the power chair platform remained very stable throughout the course, with only very little movement of the front left and right. The dummy remained stable as well in the chair, suggesting a safe ride in all conditions. The use of a cross belt did not seem to improve the safety of the dummy or the movements of the power chair. The distance between the passenger's back and the backrest was about 30 cm due to the fact that the battery pack could not fit under the backrest.

Table 11: 9 m Dennis Dart bus, four-wheeled scooter with aisle stanchion or cross belt

	Critical points on test track										
	1. Accel.	2 Lane change LEFT	3 RIGHT turn	4 Brake in right turn	5 Right to left turn	6 Lane change RIGHT	7 LEFT turn	8 Brake in left turn	9 Left to right turn	10 Accel. straight	11 Brake on straight
Wheelchair Type D four-wheeled scooter Aisle stanchion	Stable, seat sways	Stable, seat sways	Stable, seat sways	Rolls back 2.5 cm	Stable, seat sways	Stable, seat sways	Stable, seat sways	Rolls back 2.5 cm	Stable, seat sways	Stable, seat sways	Rolls back 2.5 cm
Dummy	Slight swaying in seat	Slight swaying in seat	Leans strongly to aisle	No contact with backrest or rebound	Swings from aisle to wall	Swings strongly from left to right	Leans against wall	No contact with backrest or rebound	Leans strongly into aisle	Slight swaying in seat	No contact with backrest or rebound
Wheelchair Type D four-wheeled scooter Cross belt	Stable, seat sways	Stable, seat sways	Stable, seat sways	Rolls back 2.5 cm	Stable, seat sways	Stable, seat sways	Stable, seat sways	Rolls back 2.5 cm	Stable, seat sways	Stable, seat sways	Rolls back 2.5 cm
Dummy	Sways slightly left and right	Sways strongly left and right	Leans strongly into aisle	No contact with backrest or rebound	Leans to wall	Sways strongly left and right	Leans against wall	Head misses backrest. Backrest too low	Leans strongly into aisle	Sways slightly left and right	Head misses backrest. Backrest too low

The tests showed that the power platform of the four-wheeled scooter remained very stable during the manoeuvres. The seat is mounted on a single column and tended to sway constantly with a dummy in the seat. These momentums can add to extreme movements of the upper body and resulted in concern for safety, as indicated in the shaded areas. The use of a cross belt did not seem to improve the situation since it cannot restrain the passenger's upper body movements. The distance between the passenger's back and the backrest was about 30 cm due to the fact that the battery pack could not fit under the backrest.

Table 12: 9 m Dennis Dart bus, electric wheelchair with aisle stanchion or cross belt

	Critical points on test track										
	1. Accel.	2 Lane change LEFT	3 RIGHT turn	4 Brake in right turn	5 Right to left turn	6 Lane change RIGHT	7 LEFT turn	8 Brake in left turn	9 Left to right turn	10 Accel. straight	11 Brake on straight
Wheelchair Type E Electric Aisle stanchion	Stable	Stable	Front moves slightly toward aisle	Front wheels lift, roll back 8 cm	Front moves toward wall	Stable	Front moves against wall	Front wheels lift, roll back 8 cm	Front moves 20 cm into aisle	Stable	Front wheels lift, roll back 8 cm
Dummy	Stable	Stable	Stable	Head contacts backrest and rebounds	Stable	Stable	Stable	Head contacts backrest and rebounds	Stable	Stable	Head contacts backrest and rebounds
Wheelchair Type E Electric Cross belt	Stable	Stable	Stable	Front wheels lift	Moves against wall	Stable	Stable	Front wheels lift	Stable	Stable	Front wheels lift
Dummy	Stable	Stable	Front wheels lift	Head contacts backrest and rebounds	Stable	Stable	Stable	Head contacts backrest and rebounds	Stable	Stable	Head contacts backrest and rebounds

The distance between the passenger's back and the backrest was about 25 cm due to the fact that the battery pack could not fit under the backrest. The electric wheelchair presented a very stable positioning, except during braking, when the front wheels lifted. The movements of the dummy indicated a stable ride as well, but with the front wheels lifting about 5 cm momentarily during braking. It must be determined what impact the lifting of the front wheels will have on the passenger. The cross belt did to seem to restrain the movements of the chair or the dummy any more than the aisle stanchion.

Table 13: 10.5 m Dennis Dart bus, manual wheelchair with aisle stanchion or cross belt

	Critical points on test track										
	1. Accel.	2 Lane change LEFT	3 RIGHT turn	4 Brake in right turn	5 Right to left turn	6 Lane change RIGHT	7 LEFT turn	8 Brake in left turn	9 Left to right turn	10 Accel. straight	11 Brake on straight
Wheelchair Type A Manual Aisle stanchion	Stable	Stable	Front moves to wall, rear left wheel lifts	Front wheels lift, rolls back 5 cm	Moves toward wall	Stable	Right rear wheel lifts	Front wheels lift, rolls back 5 cm	Front moves against wall, right rear wheel lifts	Stable	Front wheels lift, rolls back 5 cm
Dummy	Stable	Stable	Leans against wall	Head contacts backrest and rebounds	Leans toward aisle	Stable	Leans toward aisle	Head contacts backrest and rebounds	Leans against wall	Stable	Head contacts backrest and rebounds
Wheelchair Type A Manual Cross belt	Stable	Stable	Front moves toward wall	Front wheels lift, rolls back 5 cm	Stable	Stable	Stable	Front wheels lift, rolls back 5 cm	Front moves against wall, right rear wheel lifts	Stable	Front wheels lift; rolls back 5 cm
Dummy	Stable	Stable	Stable	Head contacts backrest and rebounds	Stable	Stable	Slightly leans toward aisle	Head contacts backrest and rebounds	Moves to wall and back	Stable	Head contacts backrest and rebounds

Conditions (Tables 13 –15):

10.5 m Dennis Dart low-floor bus

Rear-facing system located at roadside

Distance from passenger's back to backrest about 25 cm

Backrest equipped with jump seat

Wheelchairs and scooters tested with their brakes applied

The manual wheelchair in the 10.5 m Dennis Dart experienced some lifting of its rear wheels while cornering and some lifting of its front wheels during braking, as indicated in the shaded areas. As a result, the dummy was leaning either into the aisle or against the wall, depending on which of the rear wheels lifted.

Table 14: 10.5 m Dennis dart bus, three-wheeled scooter with aisle stanchion or cross belt

	Critical points on test track										
	1. Accel.	2 Lane change LEFT	3 RIGHT turn	4 Brake in right turn	5 Right to left turn	6 Lane change RIGHT	7 LEFT turn	8 Brake in left turn	9 Left to right turn	10 Accel. straight	11 Brake on straight
Wheelchair Type B three-wheeled scooter Aisle stanchion	Stable, seat sways	Stable, seat sways	Front moves toward wall	Rolls back 5 cm	Stable, seat sways	Stable, seat sways	Stable, seat sways	Rolls back 5 cm	Left rear wheel lifts	Stable, seat sways	Front wheel lifts, rolls back 5 cm
Dummy	Stable, seat sways	Leaning left and right	Leaning toward wall	Head contacts backrest and rebounds	Leans to aisle	Stable, seat sways	Leans strongly into aisle	Head misses backrest and rebounds	Contact with bus wall	Stable, seat sways	Head contacts backrest and rebounds
Wheelchair Type B three-wheeled scooter Cross belt	Stable, seat sways	Stable, seat sways	Stable, seat sways	Rolls back 5 cm	Left rear wheel lifts	Stable, seat sways	Right rear wheel lifts	Rolls back 5 cm	Right rear wheel lifts	Stable, seat sways	Rolls back 5 cm
Dummy	Stable, seat sways	Stable, seat sways	Leans toward wall	Head contacts backrest and rebounds	Leans toward aisle	Swaying left and right	Leans strongly into aisle	Head misses backrest and rebounds	Contacts wall and rebounds	Stable, seat sways	Head contacts backrest and rebounds

Tests showed that the scooter platform was somewhat unstable in cornering situations where either of the rear wheels lifted. During braking, the front wheel lifted as well. As a result of the single column-mounted seat, constant swaying of the passenger was observed. When cornering, this also resulted in some severe tipping. The areas indicating that the head missed the backrest during braking resulted from the upper body leaning into the aisle in the previous manoeuvre.

Table 15: 10.5 m Dennis Dart bus, electric wheelchair with aisle stanchion or cross belt

	Critical points on test track										
	1. Accel.	2 Lane change LEFT	3 RIGHT turn	4 Brake in right turn	5 Right to left turn	6 Lane change RIGHT	7 LEFT turn	8 Brake in left turn	9 Left to right turn	10 Accel. straight	11 Brake on straight
Wheelchair Type E Electric Aisle stanchion	Stable	Stable	Stable	Front wheels lift, rolls back 2.5 cm	Stable	Stable	Moves 45° into aisle	Front wheels lift, rolls back 2.5 cm	Stable	Stable	Front wheels lift, rolls back 2.5 cm
Dummy	Stable	Stable	Stable	Head contacts backrest and rebounds	Stable	Stable	Moves 45° toward aisle	Head misses backrest and rebounds	Stable	Stable	Head contacts backrest and rebounds
Wheelchair Type E Electric Cross belt	Stable	Stable	Stable	Front wheels lift, rolls back 5 cm	Stable	Stable	Stable	Front wheels lift, rolls back 5 cm	Stable	Stable	Front wheels lift, rolls back 5 cm
Dummy	Stable	Stable	Stable	Head contacts backrest and rebounds	Stable	Stable	Stable	Head contacts backrest and rebounds	Stable	Stable	Head contacts backrest and rebounds

The electric wheelchair presented a very stable ride, except for the front wheels lifting during braking as indicated in the shaded areas. It was observed that the dummy showed very little swaying or leaning, and remained in the upright position most of the time, indicating a safe ride.

Table 16: 12 m New Flyer, manual wheelchair and four-wheeled scooter with aisle stanchion

	Critical points on test track										
	1. Accel.	2 Lane change LEFT	3 RIGHT turn	4 Brake in right turn	5 Right to left turn	6 Lane change RIGHT	7 LEFT turn	8 Brake in left turn	9 Left to right turn	10 Accel. straight	11 Brake on straight
Wheelchair Type A Manual Aisle stanchion	Stable	Stable	Stable	Rolls back 5 cm	Stable	Stable	Front moves slightly toward wall	Rolls back 5 cm	Front moves slightly toward aisle	Stable	Rolls back 5 cm
Dummy	Stable	Stable	Stable	Head contacts backrest and rebounds	Stable	Stable	Stable	Head contacts backrest and rebounds	Stable	Stable	Head contacts backrest and rebounds
Wheelchair Type D four-wheeled scooter Aisle stanchion	Stable, seat sways	Stable, seat sways	Stable, seat sways	Rolls back 5 cm	Stable, seat sways	Stable, seat sways	Stable, seat sways	Rolls back 5 cm	Stable, seat sways	Stable, seat sways	Rolls back 5 cm
Dummy	Slight swaying left and right	Slight swaying left and right	Slight swaying left and right	Head contacts backrest and rebounds	Head hits bus wall	Slight swaying left and right	Contacts wall	Head misses backrest	Swings left and right strongly	Slight swaying left and right	Head contacts backrest and rebounds

Conditions (Tables 16-18):

12 m New Flyer low-floor bus

Rear-facing system located at curbside

Distance from passenger's back to backrest about 20-25 cm

Large lateral distance from backrest to wall, due to heating duct location

Wheelchairs and scooters tested with their brakes applied

Tests showed that the manual wheelchair remained very stable during all manoeuvres, as well as the dummy. No test was conducted with a cross belt since the aisle stanchion seemed to be sufficient.

The heavy power platform of the four-wheeled scooter remained very stable during the tests, but the single-column mounted seat constantly swayed with the weight of the dummy, and in some instances, the momentum would swing the dummy strongly against the wall or into the aisle. No test was conducted with a cross belt since this would restrain only the movements of the platform and the dummy's legs, but not the dummy's upper body movements.

Table 17: 12 m New Flyer bus, three-wheeled scooter with aisle stanchion or cross belt

	Critical points on test track										
	1. Accel.	2. Lane change LEFT	3. RIGHT turn	4. Brake in right turn	5. Right to left turn	6. Lane change RIGHT	7. LEFT turn	8. Brake in left turn	9. Left to right turn	10. Accel. straight	11. Brake on straight
Wheelchair Type B three-wheeled scooter Aisle stanchion	Stable, seat sways	Right rear wheel lifts	Front end moves toward aisle	Rolls back 8 cm	Front end contacts wall	Right rear wheel lifts	Front contacts wall, right rear wheel lifts	Rolls back 8 cm	Front moves to aisle; left rear wheel lifts	Stable, seat sways	Rolls back 8 cm
Dummy	Sways left and right	Bounces strongly from wall to aisle	Leans strongly into aisle	Head contacts backrest and rebounds	Contacts wall	Bounces strongly from left to right	Contacts wall	Head misses backrest	Bounces strongly left and right	Sways left and right	Head contacts back rest and rebounds
Wheelchair Type B three-wheeled scooter Cross belt	Stable, seat sways	Right rear wheel lifts	Stable, seat sways	Rolls back 5 cm	Front contacts wall, right rear wheel lifts	Left and right rear wheels lift	Right rear wheel lifts	Rolls back 5 cm	Right rear wheel lifts	Stable, seat sways	Rolls back 5 cm
Dummy	Sways left and right	Bounces from wall to aisle	Leans strongly into aisle	Head misses backrest	Contacts wall and bounces back	Sways left and right	Contacts wall strongly	Head misses backrest	Bounces strongly from wall to aisle	Sways left and right	Head misses backrest

The tests showed a great number of areas of concern with the wheelchair and the dummy. The scooter's rear wheels lift in turns and it moves against the wall as well as into the aisle. The dummy bounces strongly from one side to the other in turns and the head misses the backrest in braking situations. Since the seat is mounted on one column, there is constant swaying, which results in the dummy's swinging and bouncing. The cross belt did not improve the situation.

Table 18: 12 m New Flyer bus, power wheelchair with aisle stanchion

	Critical points on test track										
	1. Accel.	2 Lane change LEFT	3 RIGHT turn	4 Brake in right turn	5 Right to left turn	6 Lane change RIGHT	7 LEFT turn	8 Brake in left turn	9 Left to right turn	10 Accel. straight	11 Brake on straight
Wheelchair Type C Power chair Aisle stanchion	Stable	Front moves slightly left and right	Stable	Rolls back 2.5 cm	Front moves toward wall	Stable	Stable	Rolls back 2.5 cm	Stable	Stable	Rolls back 2.5 cm
Dummy	Stable	Stable	Stable	Head contacts backrest and rebounds	Stable	Stable	Stable	Head contacts backrest and rebounds	Stable	Stable	Head contacts backrest and rebounds

The power chair showed to be very stable under all testing conditions. The dummy experienced very little movement as well, an indication that this chair would provide a safe ride. There were no areas of concern shown in the tests.

Table 19: 12 m double-decker bus, three-wheeled scooter and manual wheelchair with cross belt

	Critical points on test track										
	1. Accel.	2 Lane change LEFT	3 RIGHT turn	4 Brake in right turn	5 Right to left turn	6 Lane change RIGHT	7 LEFT turn	8 Brake in left turn	9 Left to right turn	10 Accel. straight	11 Brake on straight
Wheelchair Type B three- wheeled scooter Cross belt	Seat sways slightly	Seat sways slightly	Front moves to wall	Rolls back about 8 cm	Tips slightly toward aisle	Seat sways slightly	Seat sways slightly	Rolls back about 10 cm	Right rear wheel lifts	Seat sways slightly	Rolls back about 8 cm
Dummy	Stable	Leans left and right	Leans left	Head and back contact backrest and rebound	Leans toward aisle	Leans left and right	Leans into aisle	Head misses backrest and rebounds	Leans left and right	Stable	Head and back contact backrest and rebound
Wheelchair Type A Manual Cross belt	Stable	Stable	Front contacts wall	Front wheels lift about 2.5 cm	Stable	Stable	Stable	Front wheels lift about 2.5 cm	Stable	Stable	Front wheels lift about 2.5 cm
Dummy	Stable	Stable, leans toward wall	Leans toward wall	Head and back contact backrest and rebound	Leans slightly left and right	Leans slightly left and right	Stable	Head and back contact backrest and rebound	Leans slightly left and right	Stable	Head and back contact backrest and rebound

Conditions (Tables 19-20):

12 m double-decker Dennis Trident bus

Rear-facing system located at roadside

No aisle stanchion

Cross belt

Backrest equipped with jump seat

Distance to backrest from 25-30 cm

Wheelchairs and scooters tested with their brakes applied

In the double-decker bus, the three-wheeled scooter tipped slightly only once in the turn from left to right coming out of the left circle. The seat swayed slightly and the dummy leaned into the aisle in the left circle. In the braking that followed, the dummy's head missed the backrest.

The dummy and the manual wheelchair remained stable, but the front wheels lifted in all three brake situations.

Table 20: 12 m double-decker bus, power wheelchair, and four-wheeled scooter with cross belt

	Critical points on test track										
	1. Accel.	2. Lane change LEFT	3. RIGHT turn	4. Brake in right turn	5. Right to left turn	6. Lane change RIGHT	7. LEFT turn	8. Brake in left turn	9. Left to right turn	10. Accel. straight	11. Brake on straight
Wheelchair Type C Power chair Cross belt	Stable	Stable	Stable	Front wheels lift about 2.5 cm	Stable	Stable	Stable	Front wheels lift about 2.5 cm	Front moves toward wall	Stable	Front wheels lift about 2.5 cm
Dummy	Stable	Leans slightly left and right	Stable	Head and back contact backrest and rebound strongly	Leans toward aisle	Leans left and right	Leans toward aisle	Head and back contact backrest and rebound strongly	Leans toward wall	Stable	Head and back contact backrest and rebound strongly
Wheelchair Type D four-wheeled scooter cross belt	Seat sways slightly	Seat sways slightly	Stable	Rolls back about 2.5 cm	Stable	Seat sways slightly	Stable	Rolls back about 2.5 cm	Seat sways	Stable	Rolls back about 2.5 cm
Dummy	Sways left and right	Leans left and right	Stable	Head and back contact backrest and rebound	Leans left and right	Leans left and right	Leans into aisle	Head misses backrest and rebounds	Whole body tips and falls into aisle DANGER	Stable	Head and back contact backrest and rebound

The power chair remained stable during the test, except for the front wheels lifting in all three braking situations. Because there was a large distance between the backrest of the power chair and the rear-facing backrest, the dummy's rebound after braking was very strong.

In the four-wheeled scooter the seat swayed slightly, but the power base remained very stable with a very small rollback during and after braking. When turning from the left circle into the right, the dummy tipped and fell into the aisle, indicating a dangerous situation.

Summary of Observations

Observations of the performance tests indicated that the most stable wheelchairs were the manual, the power and the electric chairs. The seats of these three chairs are mounted directly onto their chair frames and platforms to form one solid unit. The three-wheeled and four-wheeled scooter power platforms remained stable during the tests, but the single-column seat mounting resulted in severe swaying of the dummy. This was even more evident in the case of the 12 m New Flyer bus, where the distance from the bus wall to the dummy was greater than in other buses due to its heating duct design. This allowed the dummy to sway severely from side to side, moving the scooter with it and lifting the rear wheels.

For the scooters, the most noticeable lateral movements of the dummy occurred when the bus was coming out of the circle and changing direction, and when accelerating within the circle. The severe braking in the circles and on the straight run showed that the dummy would be in a safe position in any chair or scooter as long as it was in the upright position in front of the backrest before braking occurred. The only movement observed was the rebound of the dummy's head after contacting the backrest. It is important to note that the backrest installed in all buses did not have enough clearance from the floor to accommodate the battery packs of the scooters, electric chairs and power chairs, thus resulting in the dummy's back being too far away from the backrest.

The size and weight of the buses did not seem to have a significant effect on the results.

2.4 Sled Testing

A series of sled tests was conducted in which a mock-up of a rear-facing wheelchair stall was decelerated. An anthropomorphic test device (dummy) was placed in various mobility aids, which in turn were positioned in the wheelchair stall for the sled tests.

The aim of the sled tests was to subject the various mobility aids and the dummy to accelerations exceeding those measured during the full-scale bus crashes. The reaction of the dummy during the sled tests was studied. IVT conducted the sled tests at the PTEC's Boundary Bay facilities. The sled deceleration pulse was recorded, and standard speed video recordings of each test were made.

2.4.1 Test Equipment and Instrumentation

Deceleration Sled

The sled test facility consisted of a steel-framed sled mounted on the crash test rail at the PTEC facility. The sled was equipped with an adjustable rear-facing stall mock-up. The backrest could be raised and lowered or set at a wide range of angles.

A falling 225 kg weight on the end of a cable was used to pull the sled to speed. The sled is depicted in Figure 60.

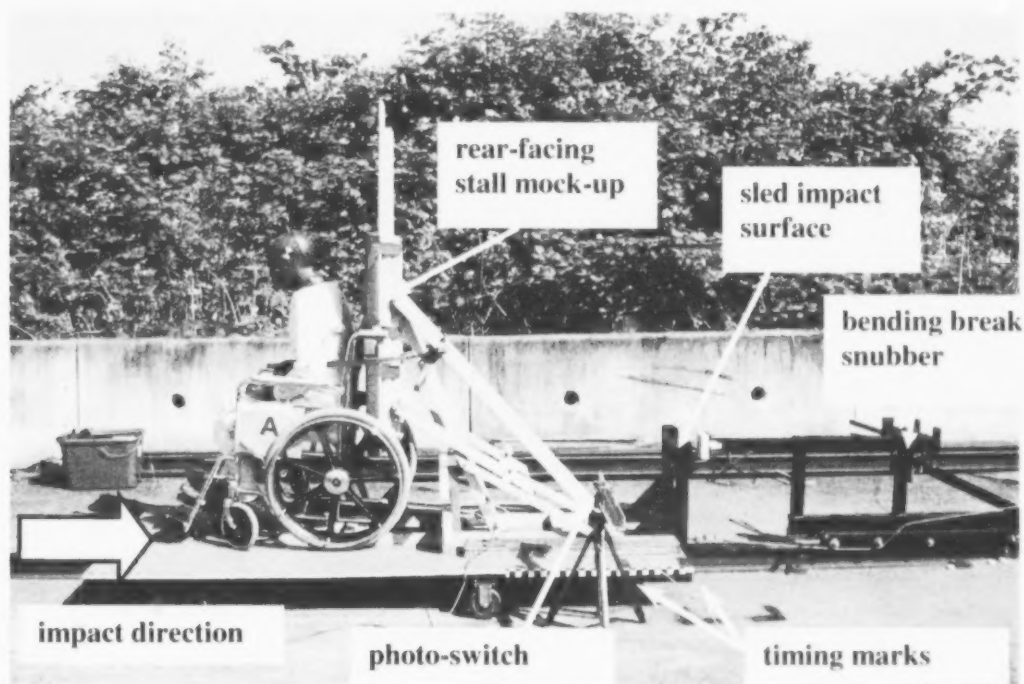


Figure 60: Sled test facility

Decelerator

A bending break snubber was used to provide the deceleration pulse for this testing. The snubber is depicted in Figure 61.

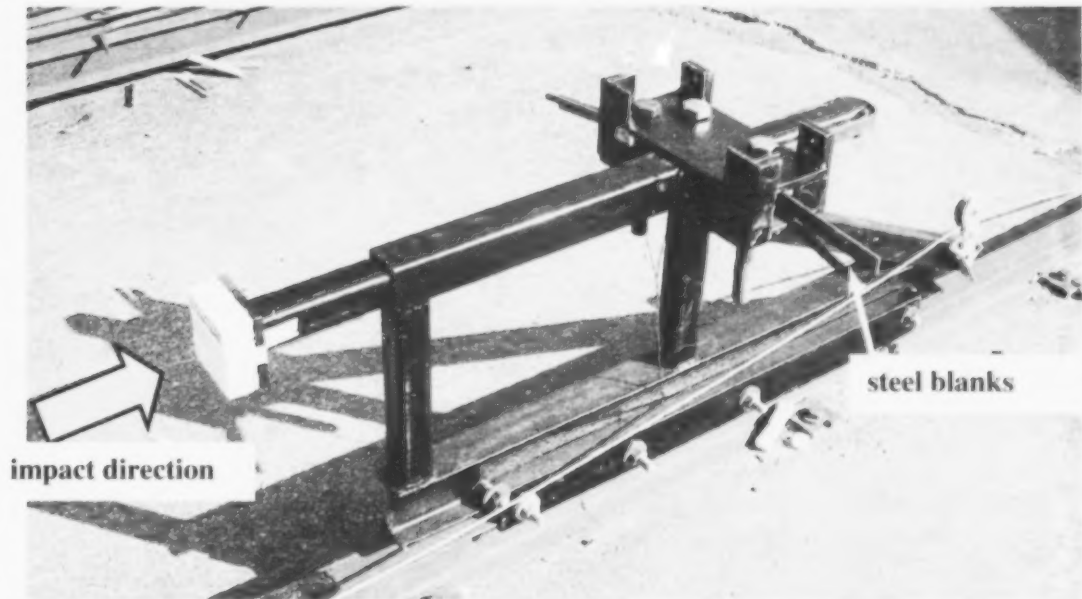


Figure 61: Bending break snubber

The snubber was loaded with two steel blanks for each test. It was found that a 1 cm square and a 0.3 cm x 2.5 cm flat produced the desired deceleration pulse. Each steel blank was used for five impacts. The bending break absorbs energy when the steel blanks are bent around the anvil, which is driven in by the decelerating sled. The steel blanks are bent into a "U" shape, as depicted in Figure 62.

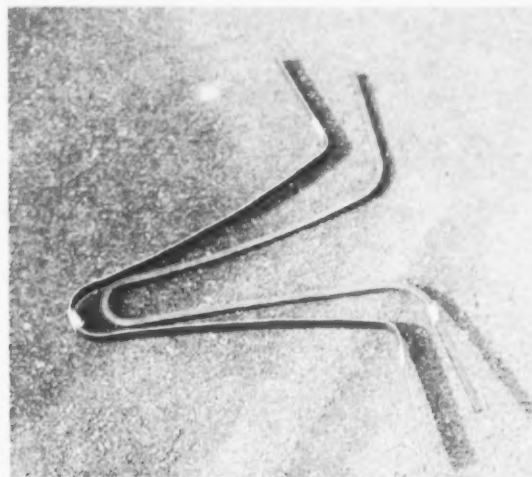


Figure 62: Bent steel blanks from bending break snubber

Speed

Retro-reflective tape was applied to the sled in two locations. As with the bus crash tests, the retro-reflective tape activated the photo switch as the sled passed by. The switch activations were recorded using a data acquisition system, and the sled speed was calculated using the time between the photo-switch activations and the retro-reflector spacing.

Accelerometer

The sled accelerometer details are as follows:

Make:	Silicon Designs
Model:	2210-100
Range:	$\pm 100\text{ g}$
Frequency Response:	0 - 2000 Hz

Portable Computer and Data Acquisition System

A notebook computer using an Intel P650 processor and operating under Windows 98 was used to collect deceleration data. A National Instruments analog-to-digital (A/D) board was used to convert accelerometer signals to digital format for storage in the notebook computer. LabVIEW software was used on the computer to control the A/D board and process the data.

Video and Photography

Testing was documented using handheld digital video cameras and a digital still camera. Vehicle information was recorded with a digital still camera.

Anthropomorphic Test Device

The same dummy as used for the performance tests was used to simulate a wheelchair occupant for these tests.

2.4.2 Sled Test Results

Four mobility devices were tested on the sled. They were identified as chairs A, B, D and E, and are described in section 2.3.1. Each mobility device was tested in five different configurations. The configurations included various stall backrest angles, and various spacing between the dummy's head and the backrest.

One objective was to produce identical deceleration pulses for all of the tests. It was found that the bending break snubber provided quite reproducible results. An example of the sled deceleration pulse is depicted in Figure 63.

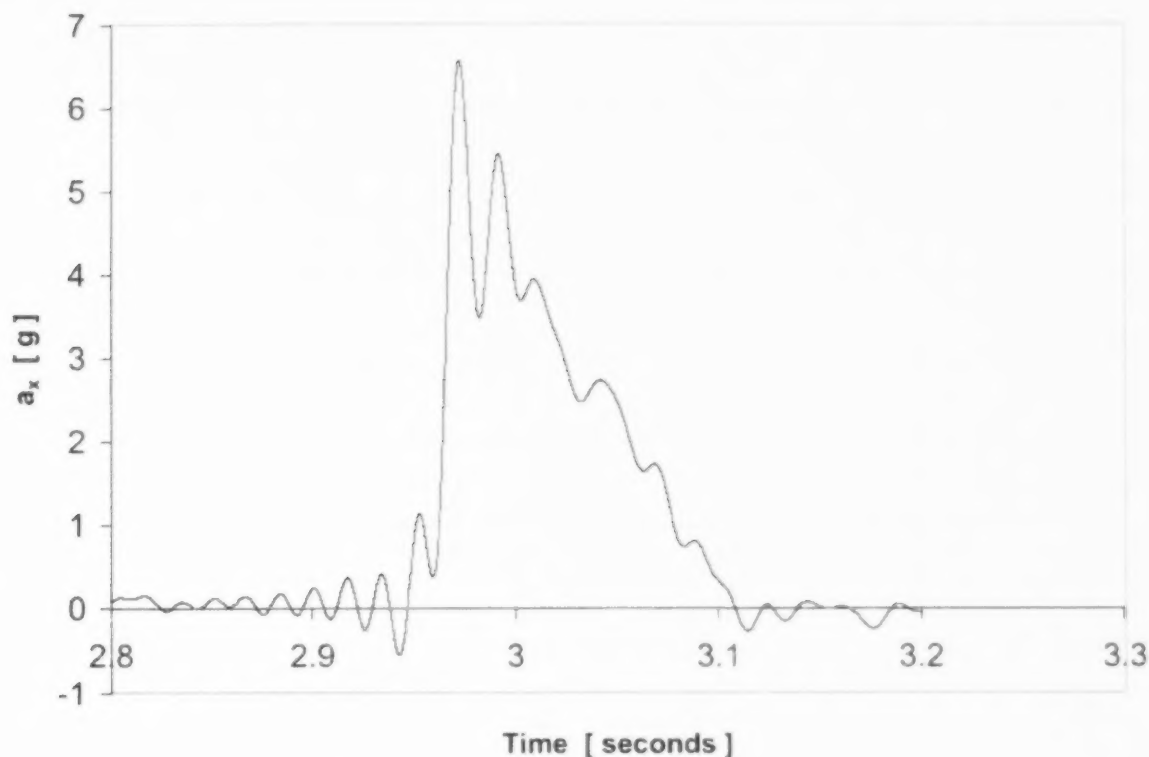


Figure 63: Example sled deceleration pulse

In Figure 63 it can be seen that the deceleration pulse exceeded 3 g for longer than 50 msec. No analysis of the dummy reactions was performed by IVT. However, in all of the tests it was noted that the dummy appeared to react favourably, and remained on the mobility device, which remained in the rear-facing stall. There was a tendency for the mobility device to rebound following the deceleration pulse.

2.4.3 Observations

Table 21: Chair A – manual

Type of chair	+ 4°	+ 8°	- 4°	Self adjusting
Chair A	Rebounds about 5 cm after impact; no wheels lift	Rebounds about 5 cm after impact; no wheels lift	Rebounds about 2.5 cm after impact; no wheels lift	No noticeable rebound
Dummy	Head and back contact backrest; head rebounds about 25 cm	Head and back contact backrest; head rebounds about 10 cm; head slides up backrest.	Head and back contact backrest; head rebounds only about 5 cm	Head and back contact backrest; head rebounds only about 5 cm

The best results were observed at -4° and with a self-adjusting backrest. There was almost no chair rebound at self-adjusting and very little head rebound at -4° and with a self adjusting backrest. No wheels lifted after impact.

Table 22: Chair B – three-wheeled scooter

Degrees of back panel inclination from vertical				
Type of chair	0°	+ 4°	+ 8°	Self adjusting
Chair B	Rebounds about 8 cm after impact; no wheels lift	Rebounds about 5 cm after impact; no wheels lift	Rebounds about 5 cm after impact; no wheels lift	Rebounds about 5 cm after impact; no wheels lift
Dummy	Head and back contact backrest; head rebounds about 20 cm	Head and back contact backrest; head rebounds about 15 cm	Head and back contact backrest; head rebounds about 15 cm; head slides up backrest	Head and back contact backrest; head rebounds about 20 cm

During these tests, no batteries became loose. In the self-adjusting position the backrest remains at about -4° after impact. At +4° and +8° the head rebound was observed to be less then in the other positions.

Table 23: Chair D – four-wheeled scooter

Degrees of back panel inclination from vertical			
Type of chair	0°	+ 4°	+ 8°
Chair D	Rolls back about 8 cm; no lifting of wheels	Rolls back about 8 cm; no lifting of wheels	Rolls back about 5 cm; no lifting of wheels
Dummy	Head and back contact backrest; head rebounds about 10 cm	Head and back contact backrest; head rebounds about 10 cm	Head and back contact backrest; head rebounds about 8 cm; head slides up backrest

The best conditions were indicated at +8°. No batteries became loose and no wheels were lifting. Sliding up the backrest seems to absorb some of the impact energy, resulting in a lesser rebound of the head.

Table 24: Chair E – electric

Degrees of back panel inclination from vertical				
Type of chair	0°	+ 4°	+ 8°	Self adjusting
Chair E	Rolls back about 2.5 cm	Rolls back less than 2.5 cm	Rear wheels lift about 2.5 cm after impact	No roll back
Dummy	Head and back contact backrest; head rebounds about 15 cm	Head and back contact backrest; head rebounds about 8 cm; head slides up	Head and back contact backrest; head rebounds about 8 cm; head slides up	Head and back contact backrest; head rebounds about 8 cm

In these tests, no batteries became loose. The rear wheels lifted in the +8° position. In the self-adjusting position, the backrest remained in about the -4° position after impact. The + 4°, +8° and the self-adjusting positions seem to be the best for this wheelchair.

Summary of observations

There were no conclusive results found for the correct back angle applying to all chair types. The manual and electric chair seemed to perform best in the -4° , $+8^{\circ}$ and the self-adjusting positions, while the scooters had less rebound in the $+4^{\circ}$ and $+8^{\circ}$ positions. Sliding up the backrest seemed to absorb some of the impact energy, resulting in a lesser rebound of the head. It is noteworthy to mention that no batteries became loose during impact, and only in one instance did the rear wheels lift slightly. During these tests the dummy was not instrumented. Additional tests would be required to investigate what impact the rebound of the head would have with regard to possible injuries.

3. DISCUSSION

3.1 The Value of Standards

Standards related to mobility aid transportation help ensure that equipment used in wheelchair transportation is designed, built and used safely. The general objective of these standards is to ensure that persons with disabilities can be transported in a moving vehicle while remaining on their mobility aid, while providing a level of safety equivalent to that provided to a person in a regular passenger seat. The standards are very important to vehicle and equipment manufacturers because they provide references for strength and geometry requirements. The standards also provide regulators with the tools they need to establish regulations to ensure public safety.

3.2 Canadian Standards

There are five Canadian Standards Association (CSA) standards related to transporting mobility aids in moving vehicles.

1. CSA D409-02 – provides design and performance requirements for motor vehicles intended for transporting persons with disabilities
2. CSA D435-02 – similar to D409 but covers accessible transit buses with a gross vehicle weight rating (GVWR) of 7,000 kg or greater
3. CSA D436-03 – similar to D435 but covers intercity buses
4. CSA Z604-03 – provides design and performance requirements for transportable mobility aids such as wheelchairs and scooters
5. CSA Z605-03 – provides design and performance requirements for mobility aid securement and occupant restraint systems suitable to enable persons in Z604 type mobility aids to be safely transported in D409 vehicles.

The overall safety of persons in mobility aids being transported is governed by the least safe element in the transportation system, and hence each of the standards noted above is required to ensure a safe "system".

D409, Z604 and Z605 were developed with smaller (under 7,000 kg) vehicles as the focus and apply the same 20 g, 48 km/h crashworthiness requirements as conventional automobiles.

D435 and D436 were developed more recently in recognition that the 20 g, 48 km/h requirements were excessive for large vehicles.

3.3 CSA Standard D435-02 and this Study

CSA Standard D435-02 requires mobility aid transportation features of large accessible transit buses to be designed and to perform to ensure a safe environment to withstand frontal crash forces up to 3 g. The 3 g value was adopted by the D435 Technical Committee based on excellent transit bus accident history with standing passengers in a bus and the belief that 3 g is the maximum deceleration likely to be encountered in a frontal impact in a transit bus over 7,000 kg GVWR. Similar European standards use a value of 1 g. Over the years there has been debate over the most appropriate force to use in the standards: 1 g, 3 g, 6.7 g, or even 10 g. The CSA 3 g value reflects a balance between safety and practicality in the transit environment.

One of the purposes of this study was to perform crash testing of transit buses with cars to simulate a typical frontal crash and to determine actual impact forces in the buses. The results of this crash testing would then confirm the appropriateness of the 3 g value.

Upon validation of the 3 g value used in the standards, further testing on a sled using a rear-facing wheelchair station mock-up was done to learn more about the performance of the rear-facing design specified in CSA Standard D435-02. This testing used an anthropomorphic dummy in a variety of mobility aid types exposed to 3 g impact forces while stationed in the mock-up rear-facing wheelchair station.

In addition, performance testing was carried out using a variety of accessible in-service transit buses. The performance testing employed an anthropomorphic dummy in a variety of mobility aid types exposed to extreme driving manoeuvres on a pre-determined test track. This testing expanded the knowledge on how passengers and mobility aids react in a rear-facing wheelchair station during aggressive driving typical of an emergency situation on the road. This information will assist in future revisions of CSA Standard D435-02.

3.4 In-service Survey by OSU

A project was undertaken by a research team at Oregon State University (OSU) at the same time as this project, and it was agreed that collaboration between the two teams would result in benefits for the industry. The goal of the OSU project was to evaluate options for securements used in Bus Rapid Transit systems through: measuring vehicle dynamics, evaluating mobility-aid responses to bus motions using rear-facing systems and side-facing securement, and evaluating user responses to the concept of rear-facing systems. The results of the study indicate that accelerations during normal driving averaged substantially below that of extreme manoeuvring. In the case of forward acceleration, it was about 0.10 g with a maximum of 0.20 g. For turns, the average during normal driving was about 0.18 g, with a maximum recorded of 0.4 g. For deceleration under normal conditions, the average was 0.19 g.

The results of the survey were remarkably similar for users and potential users. Overall, approximately 70% were enthusiastic about rear-facing securement, about 10% had no opinion and about 20% did not want to use rear-facing securement.

A final report of the project has been completed [1].

4. CONCLUSIONS

- The crash tests indicated that the wheelchair occupant would only be exposed to more than 3 g for 10 msec, which is not sufficient time to result in much transference of the force to the body, and therefore the change in speed of the body is very low. The event of a frontal crash would be very rare in the urban transit environment.
- The extreme manoeuvring test results rendered a maximum of 0.5 g for deceleration in a panic brake, and 0.10 g in maximum acceleration for a 9 m bus. The other buses registered 0.8 g in a panic brake and 0.15 g in maximum acceleration. Maximum lateral acceleration was 0.25 g.
- The sled tests indicated that the different wheelchairs and the occupant would be held safely by the backrest in a 3 g crash pulse. The tests with different backrest angles were not conclusive but seemed to indicate that the occupant's rebound after impact would be favourable at +4° and with a self-adjusting back. Batteries did not become loose during these tests.
- The tests validated the 3 g figure indicated in CSA Standard D435-02 for rear-facing securements in urban buses. The load cell in the crash test indicated 2.9 g with a 12 m General Motor's bus.
- The aisle stanchion was shown to be relatively successful in preventing mobility aids from moving or tipping into the aisle during the performance testing. However, there is definitely room for improvement.
- The lateral distance between the passenger's shoulder and the bus wall was too large in the 12 m New Flyer bus and allowed for swaying and tipping of the passenger's upper body in sharp turns.
- The rear-facing backrest structure, designed to CSA Standard D435-02 specifications, adequately controlled the reactions of the mobility aid and the dummy during the 3 g sled testing.
- Although the existing backrest structures in the buses were consistent with CSA Standard D435-02, the vertical distance from the floor to the back panel was too short and did not allow for the battery packs to fit underneath, thus preventing the passenger's back from getting as close as possible to the backrest.

- The backrest panel used in the sled testing was too wide to suit some wheelchairs, despite meeting CSA Standard D435-02 width specifications.
- During the sled testing impact, the dummy tended to ride up the $+4^{\circ}$ to $+8^{\circ}$ slope of the backrest specified in CSA Standard D435-02. This motion would absorb some crash energy and hence is a positive feature, but it is also evidence that the height of back panel should be generous and suit a 95th percentile person.
- In the sled testing, the plastic upholstery of the back panel seemed to decrease friction, but no friction tests were conducted.
- Some wheelchair/scooter's wheels slid on the floor during the panic brake and in curves.

5. RECOMMENDATIONS

Based on the outcome of the testing, the following recommendations are made:

Design

- An improved system to prevent the wheelchairs or scooters from moving into the aisle should be designed to further minimize lateral movement and improve user convenience.
- A system should be designed with the shortest lateral distance possible between the passenger's shoulders and the side supports.
- The backrest should be designed and installed to ensure the head and back of the passenger are positioned as close as possible to the backrest panel. There should be a horizontal space behind the back panel for the large rear wheels of wheelchairs to clear so that the passenger's back comes as close as possible to back panel.
- Vertical clearance from floor to the bottom of the back panel must be appropriate in order to allow for batteries and power packs from scooters and power chairs to fit underneath the panel and allow for the passenger's back to come as close as possible to back panel.
- The width of back panel must be appropriate to clear the handle bars of manual wheelchairs.
- The angle of the back panel should be appropriate to absorb the most energy of the passenger.
- To help control the passenger's movement during impact, the upholstery of the back panel should be high friction.
- To minimize slippage of the mobility aid on the bus floor, high-friction flooring should be used on the bus in the wheelchair compartment to increase friction for wheelchair wheels.

Operations

- The rear-facing design, as tested, was shown to be a safe system to implement into large urban buses to protect passengers using wheelchairs and scooters for normal and severe urban driving conditions, provided that the brakes of the wheelchairs/scooters are applied and that an aisle-side anti-tipping system is in place to prevent wheelchairs and scooters from moving/tipping into the aisle. Rear-facing mobility aid passengers should always be positioned as close as possible to the backrest.
- The rear-facing system should be installed as close to the bus wall as possible to keep the aisle free and to keep the passenger's upper body as close as possible to the wall for support.

Standards

- The 3 g forces as indicated in CSA Standard D435-02 were validated by the tests to be appropriate.
- The geometry of the backrest as specified should be reviewed to ensure it properly accommodates the majority of mobility aids. Based on the testing experience, the backrest would be more accommodating if its maximum width were less than the 420 mm specified and its height from the floor more than the 350 mm specified.

R&D

- Further R&D should be undertaken to:
 - Develop a more effective and efficient aisle support
 - Determine optimum back panel geometry (width, height, distance from floor)
 - Determine optimum back panel angles
 - Identify appropriate high-friction surfaces for back panel upholstery and bus floor
 - Study risk of injury to the passenger's head and body during 3 g frontal impacts when riding in the rear-facing system in a full-size bus

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